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(54) **INK CIRCULATION DEVICE AND INK EJECTION DEVICE**

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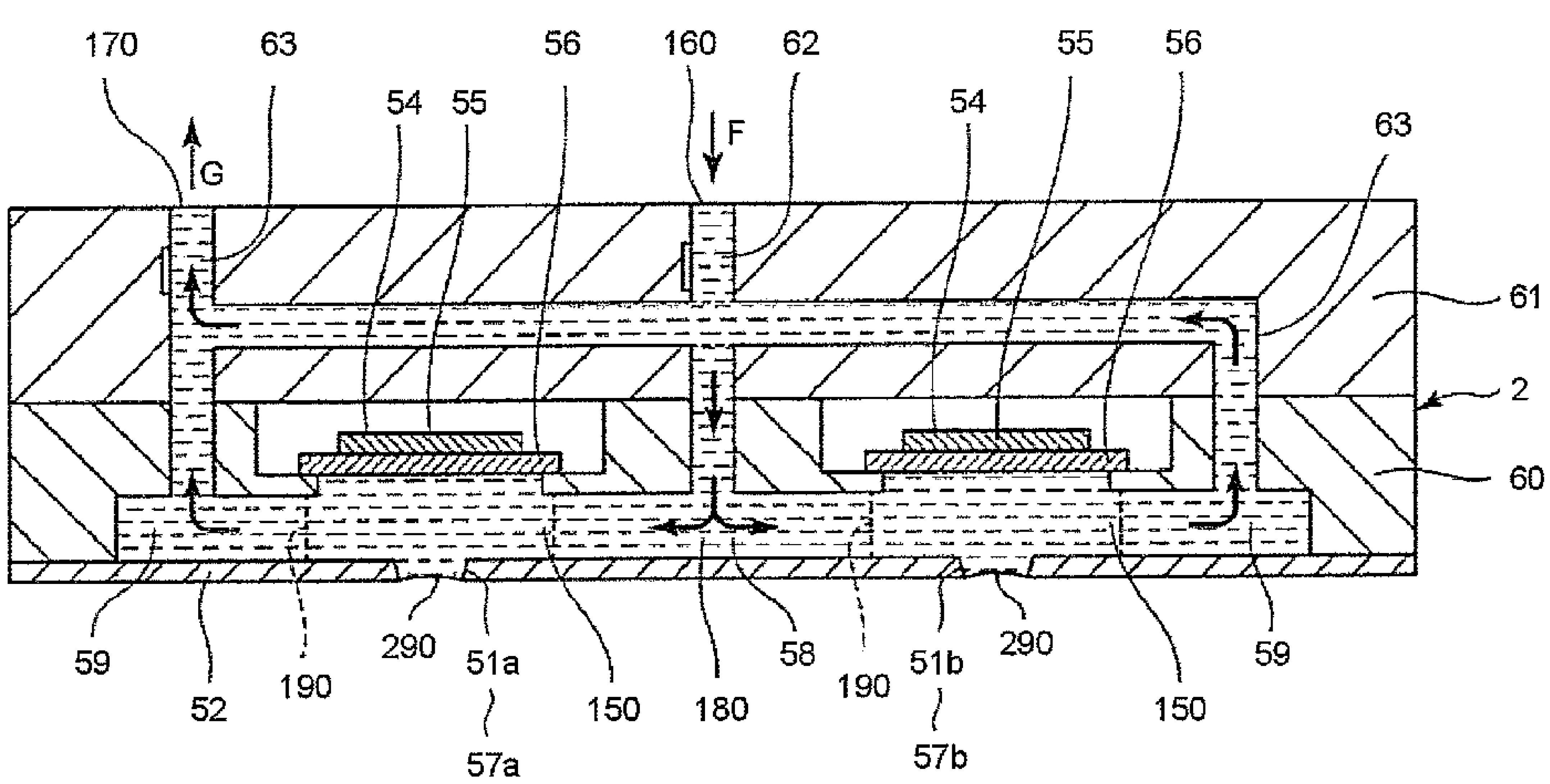
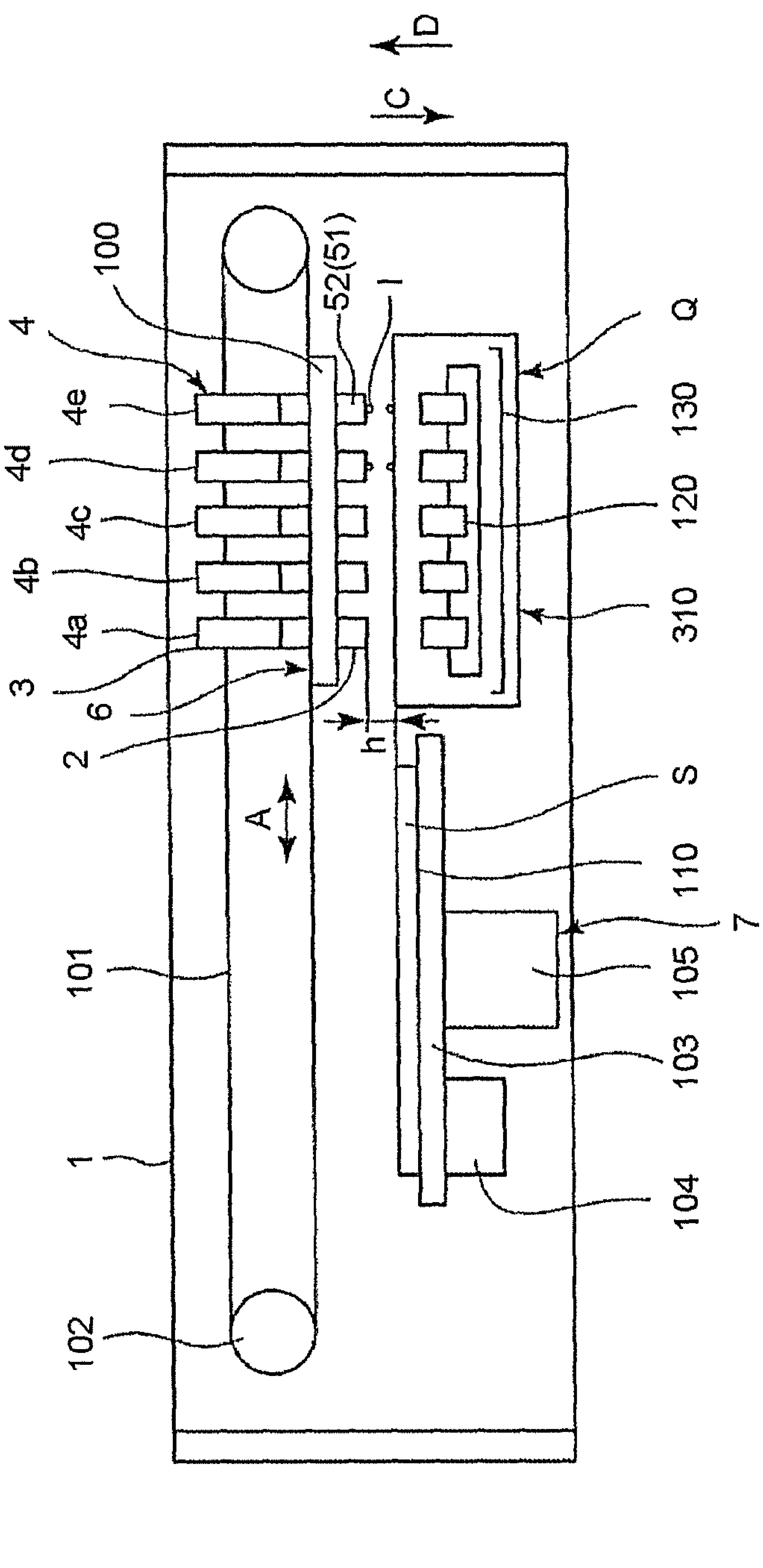
(57) **ABSTRACT**

An liquid circulation device comprises a liquid casing, a gas replenishing section and a liquid replenishing section. The liquid casing retains liquid to be supplied to a liquid ejection section for ejecting the liquid and includes a liquid chamber connected with the liquid ejection section in such a manner that the liquid can be circulated therebetween. The ink circulation device increases pressure inside of the liquid casing by replenishing the gas to the liquid casing with the gas replenishing section and replenishing the liquid to the liquid casing with the liquid replenishing section, and meets a relation $(\Delta P1*(d1)^2/L1)/(\Delta P2*(d2)^2/L2)>\mu1/\mu2$.

12 Claims, 11 Drawing Sheets





D
C
100
52(51)
I
4
Q
4e
130
4d
120
4c
4b
310
4a
3
6
2
h
S
A
110
7
101
105
103
1
104
102

FIG.1

FIG.2

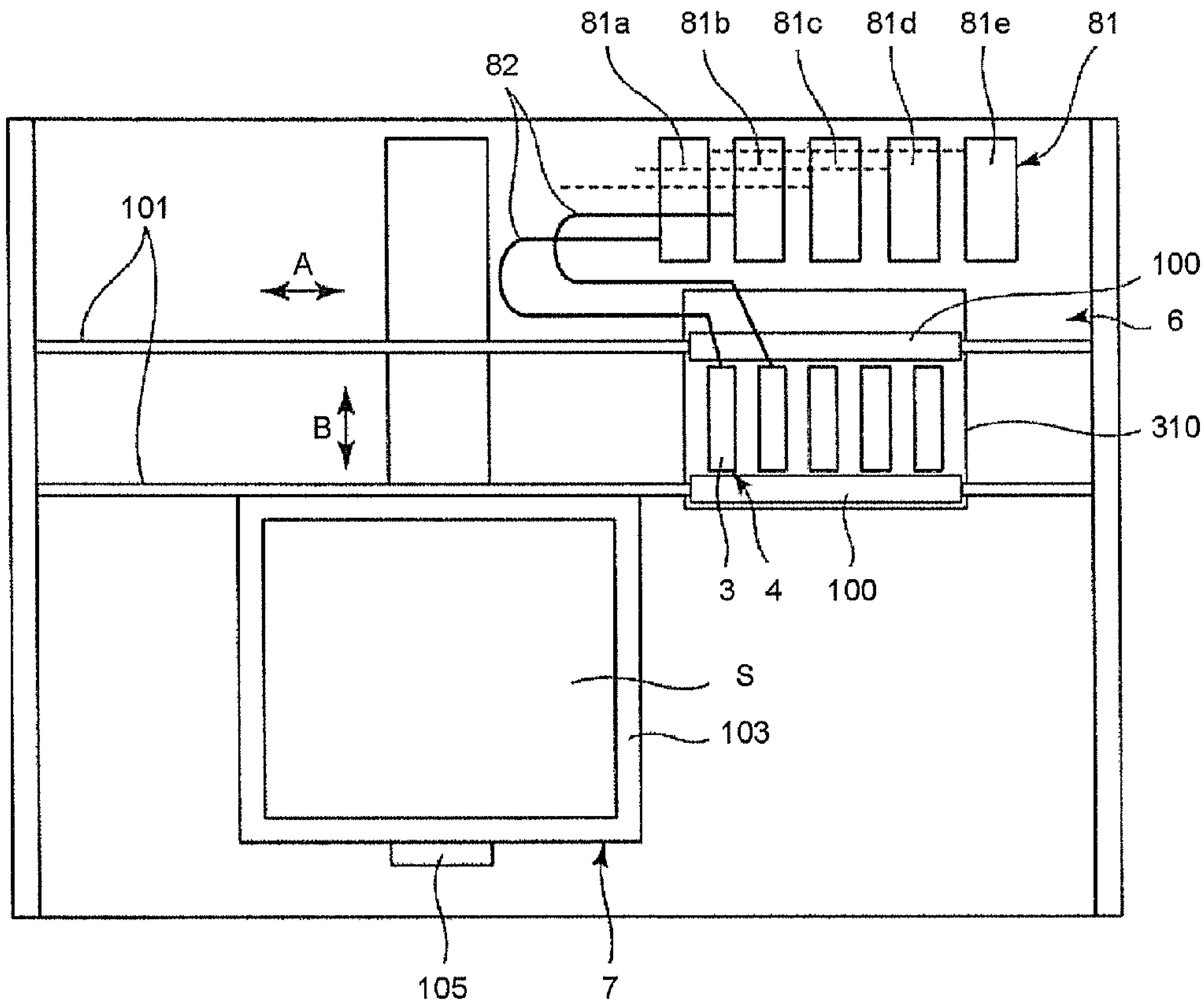


FIG.3

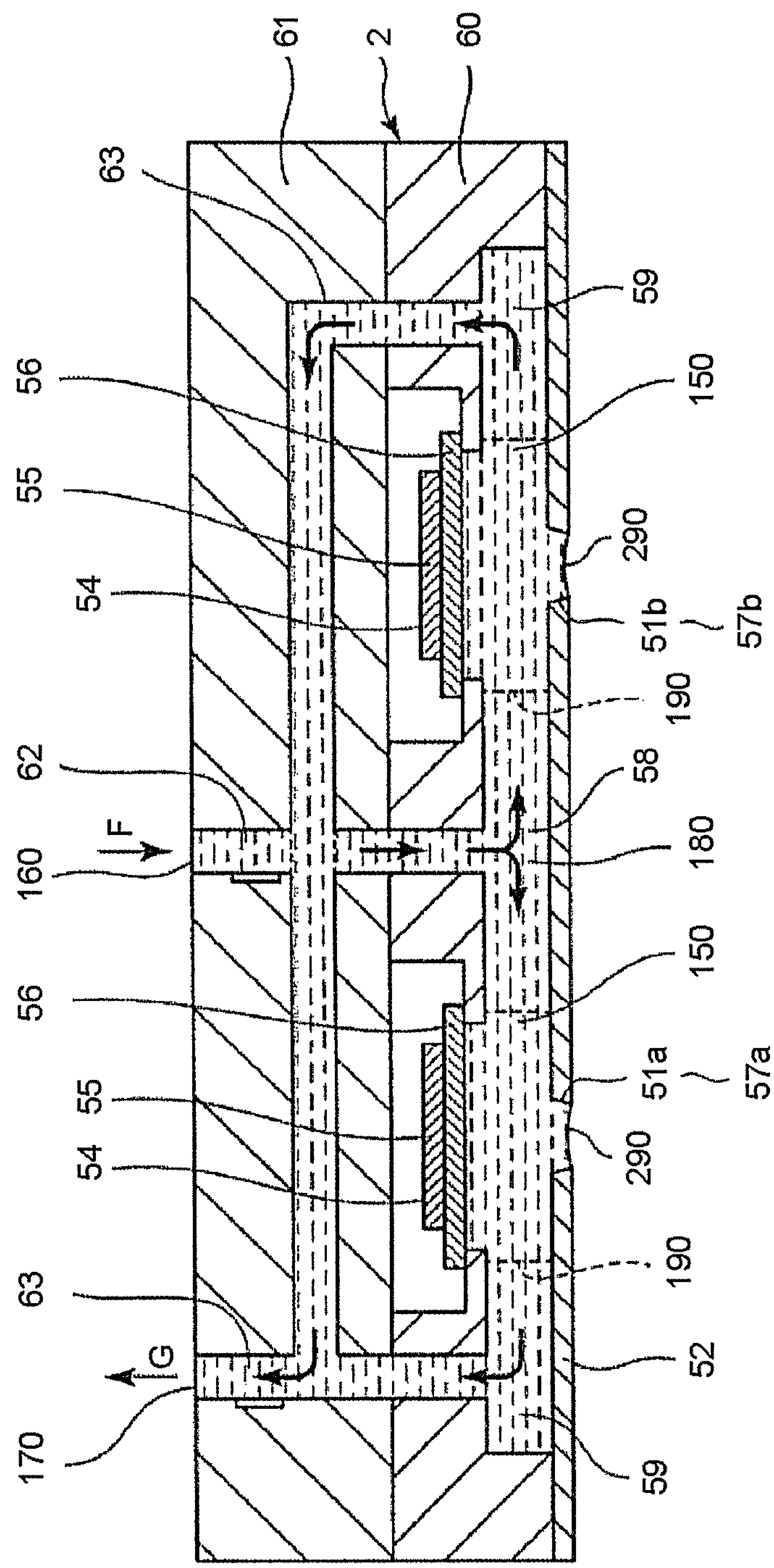

61
2
60
63
59
56
150
55
290
54
51b
57b
190
62
58
F
160
180
56
150
51a
57a
55
290
54
190
63
G
52
170
59

FIG.4

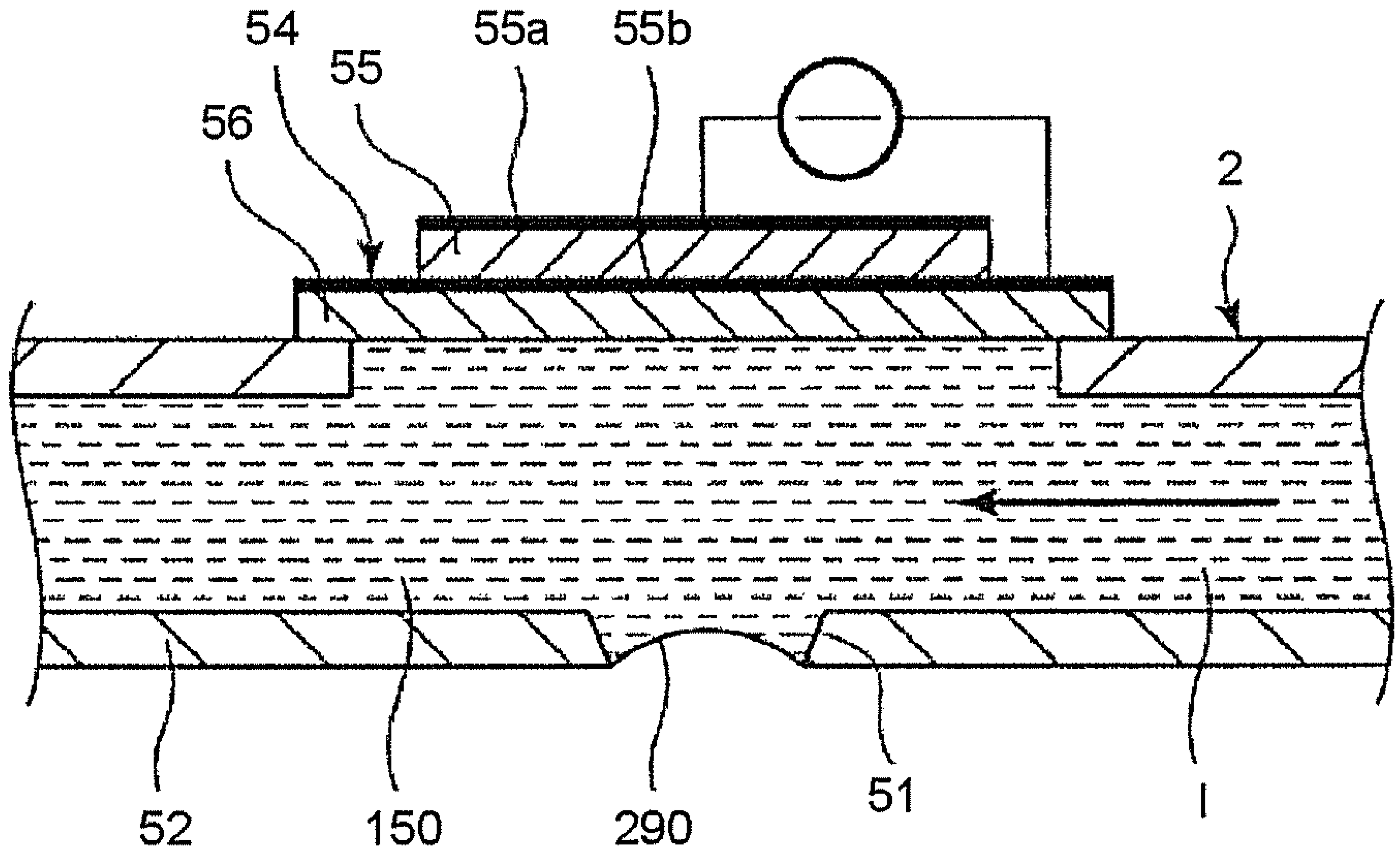

54
55a
55b
55
56
2
52
150
290
51
I

FIG.5

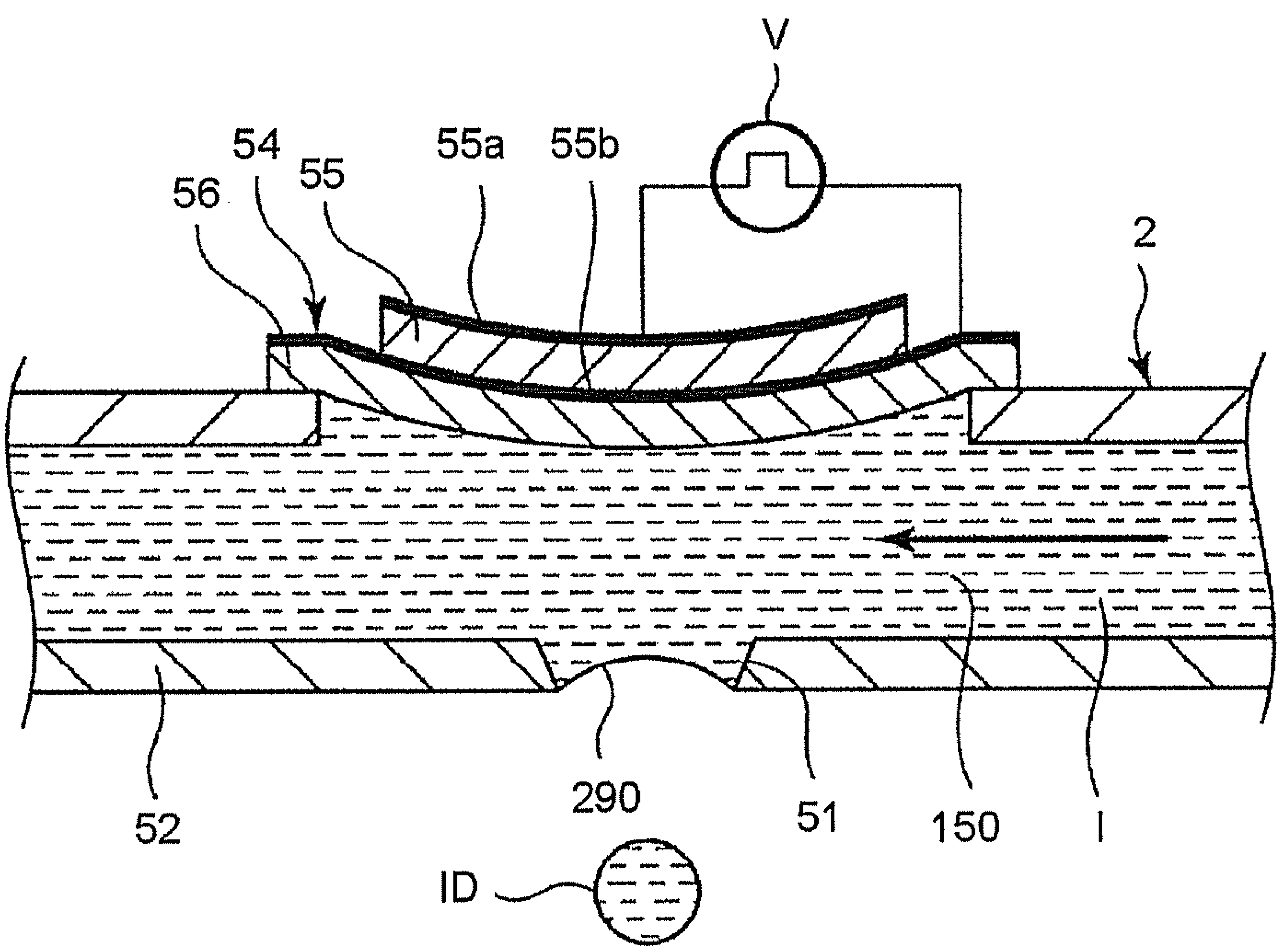
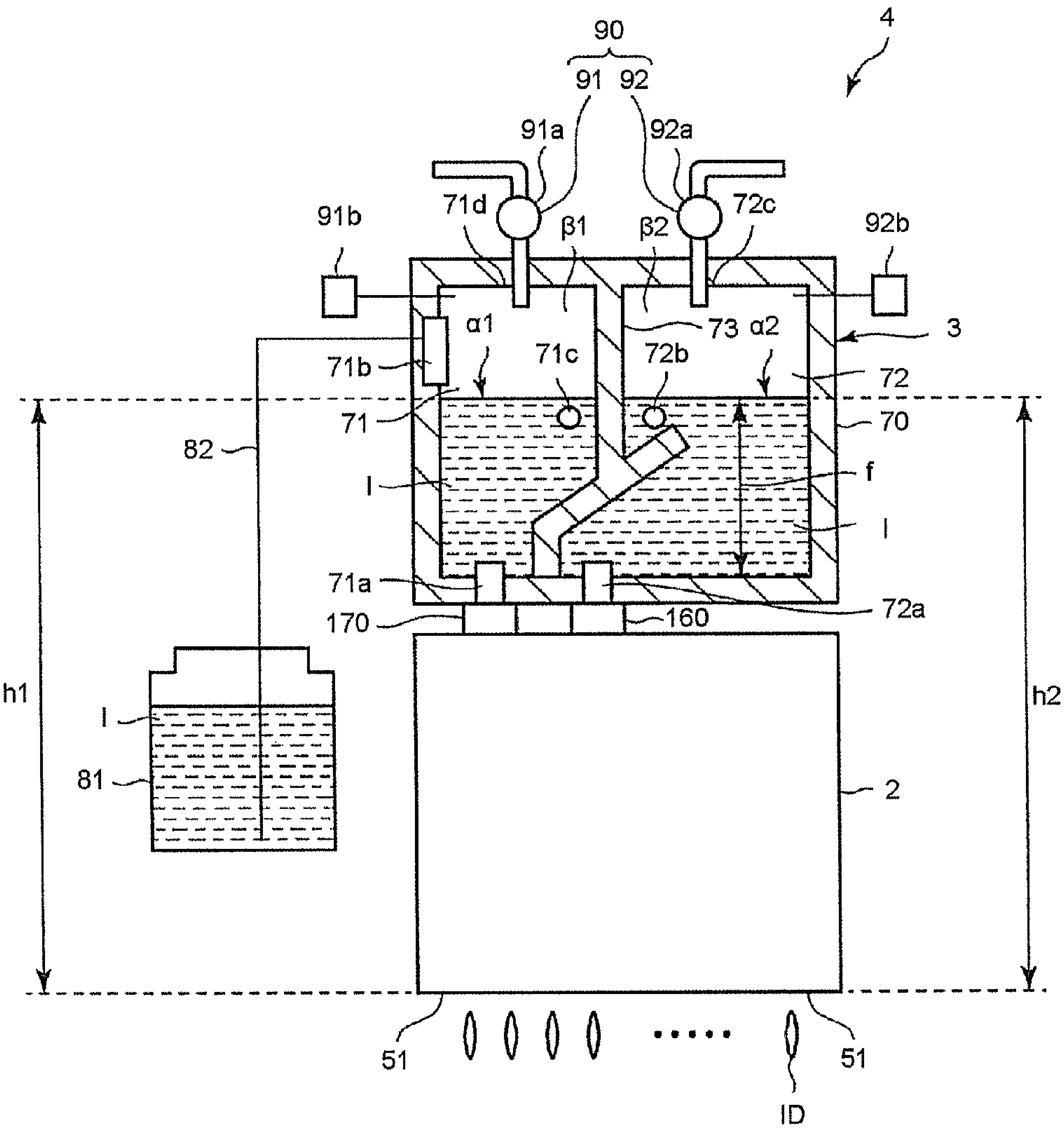

V
54
55a
55b
55
56
2
52
290
51
150
I
ID

FIG.6


90
91 92
4
91a
92a
91b
71d
β1
β2
72c
92b
73
α2
3
α1
71c
72b
71b
72
71
70
82
f
I
I
71a
72a
170
160
h1
h2
I
81
2
51
51
ID

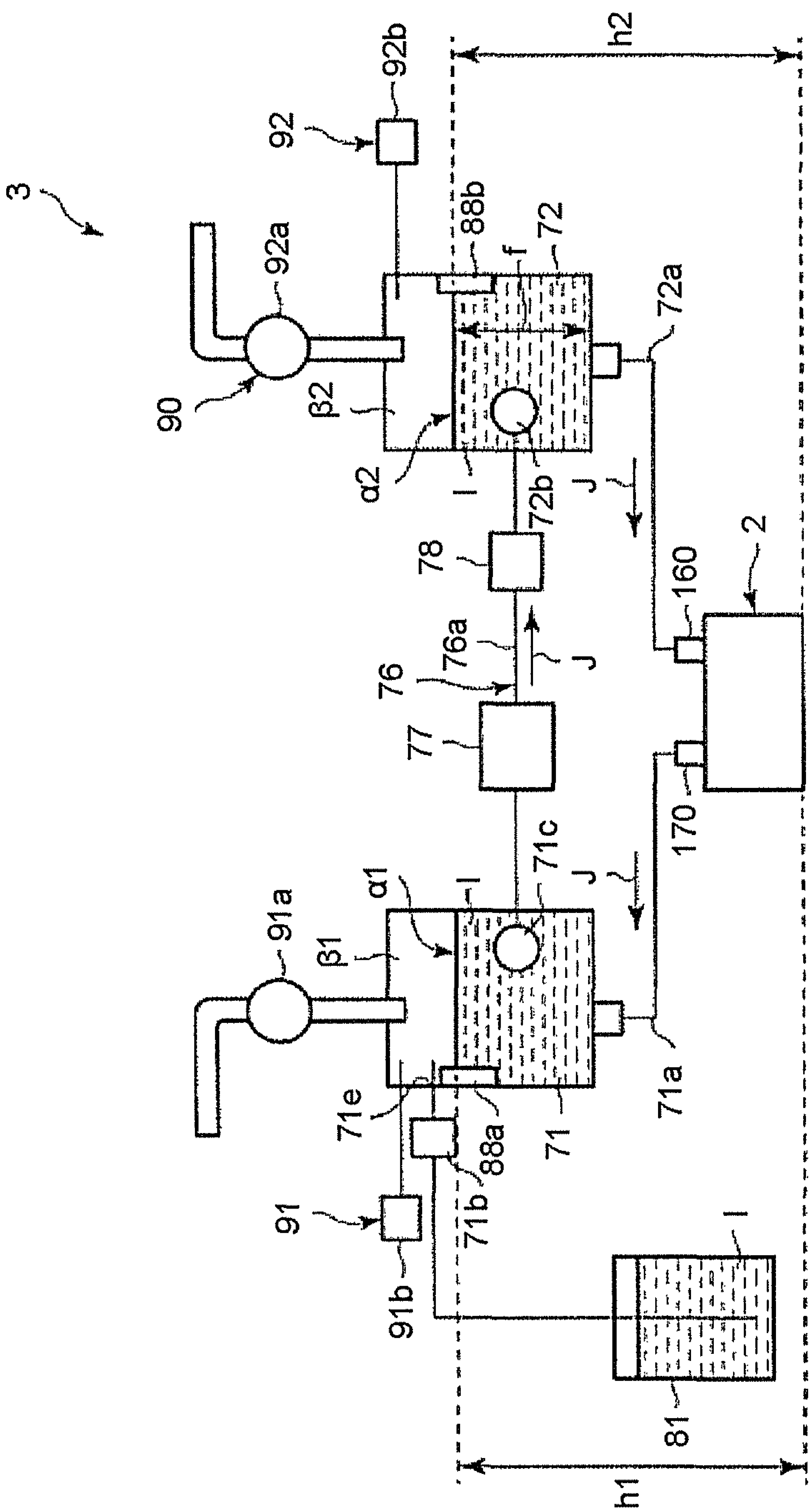

3
90
92a
92
92b
88b
f
72
72a
β2
α2
I
72b
J
78
76a
76
77
160
2
170
71c
α1
I
91a
β1
71e
88a
71
71a
71b
91
91b
81
h1
h2

FIG.7

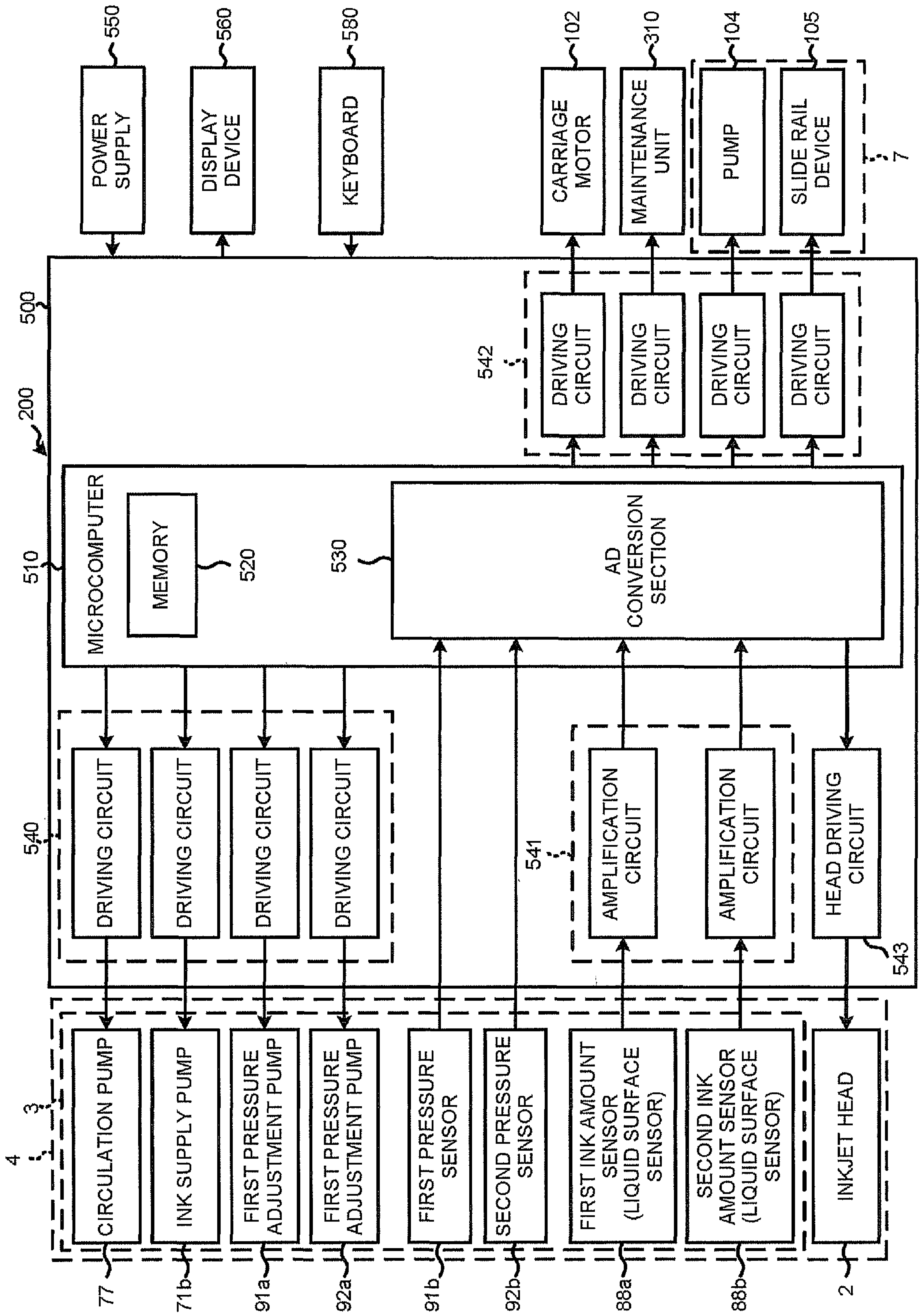
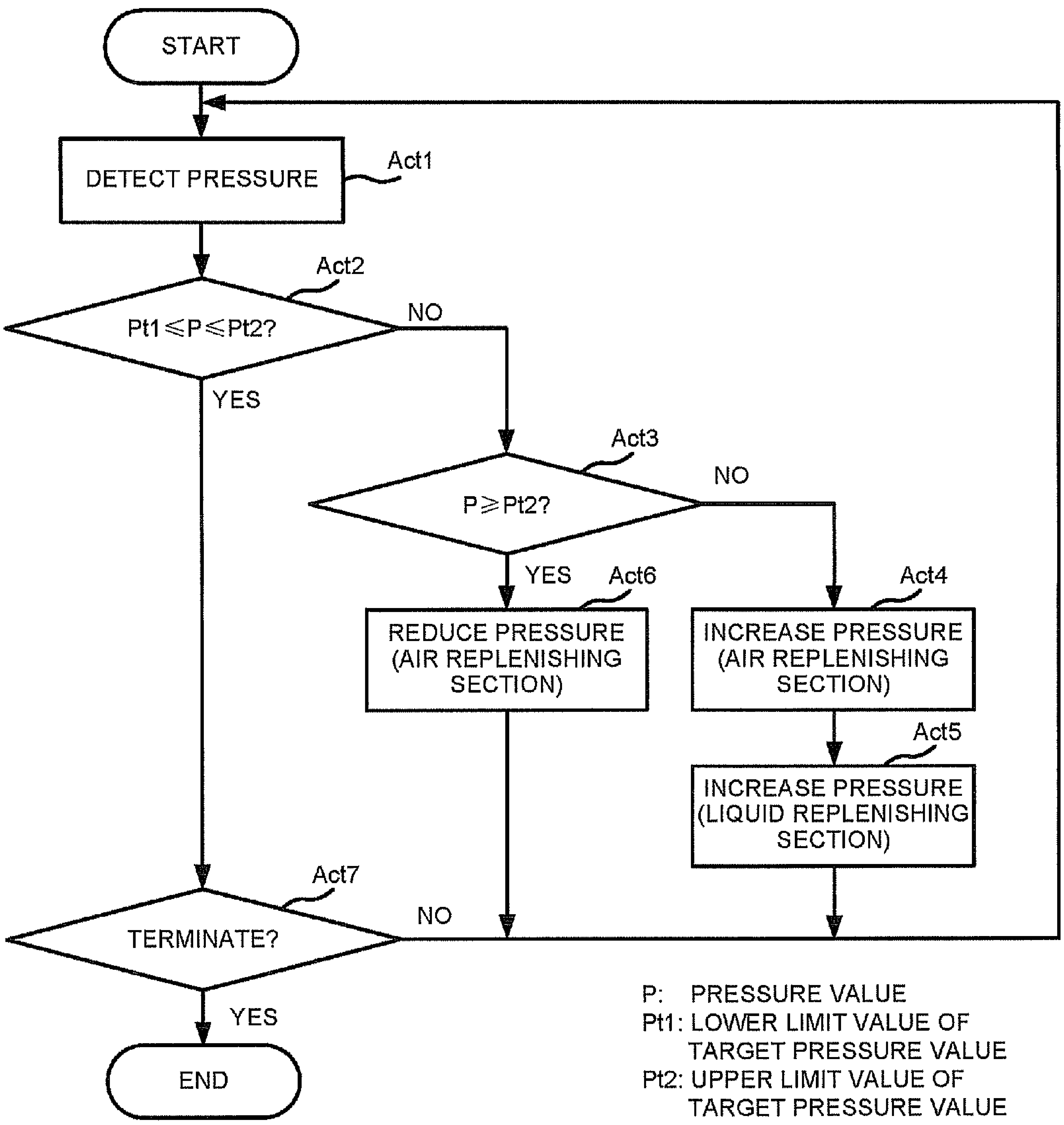

POWER SUPPLY
550
DISPLAY DEVICE
560
KEYBOARD
580
CARRIAGE MOTOR
102
MAINTENANCE UNIT
310
PUMP
104
SLIDE RAIL DEVICE
105
7
500
200
542
DRIVING CIRCUIT
DRIVING CIRCUIT
DRIVING CIRCUIT
DRIVING CIRCUIT
510
MICROCOMPUTER
MEMORY
520
530
AD CONVERSION SECTION
540
DRIVING CIRCUIT
DRIVING CIRCUIT
DRIVING CIRCUIT
DRIVING CIRCUIT
541
AMPLIFICATION CIRCUIT
AMPLIFICATION CIRCUIT
HEAD DRIVING CIRCUIT
543
4
3
CIRCULATION PUMP
77
INK SUPPLY PUMP
71b
FIRST PRESSURE ADJUSTMENT PUMP
91a
FIRST PRESSURE ADJUSTMENT PUMP
92a
FIRST PRESSURE SENSOR
91b
SECOND PRESSURE SENSOR
92b
FIRST INK AMOUNT SENSOR (LIQUID SURFACE SENSOR)
88a
SECOND INK AMOUNT SENSOR (LIQUID SURFACE SENSOR)
88b
INKJET HEAD
2

FIG.8

FIG.9



START
DETECT PRESSURE
Act1
Act2
Pt1≦P≦Pt2?
NO
YES
Act3
P≧Pt2?
NO
YES
Act6
REDUCE PRESSURE (AIR REPLENISHING SECTION)
Act4
INCREASE PRESSURE (AIR REPLENISHING SECTION)
Act5
INCREASE PRESSURE (LIQUID REPLENISHING SECTION)
Act7
TERMINATE?
NO
YES
END
P: PRESSURE VALUE
Pt1: LOWER LIMIT VALUE OF TARGET PRESSURE VALUE
Pt2: UPPER LIMIT VALUE OF TARGET PRESSURE VALUE

FIG.10

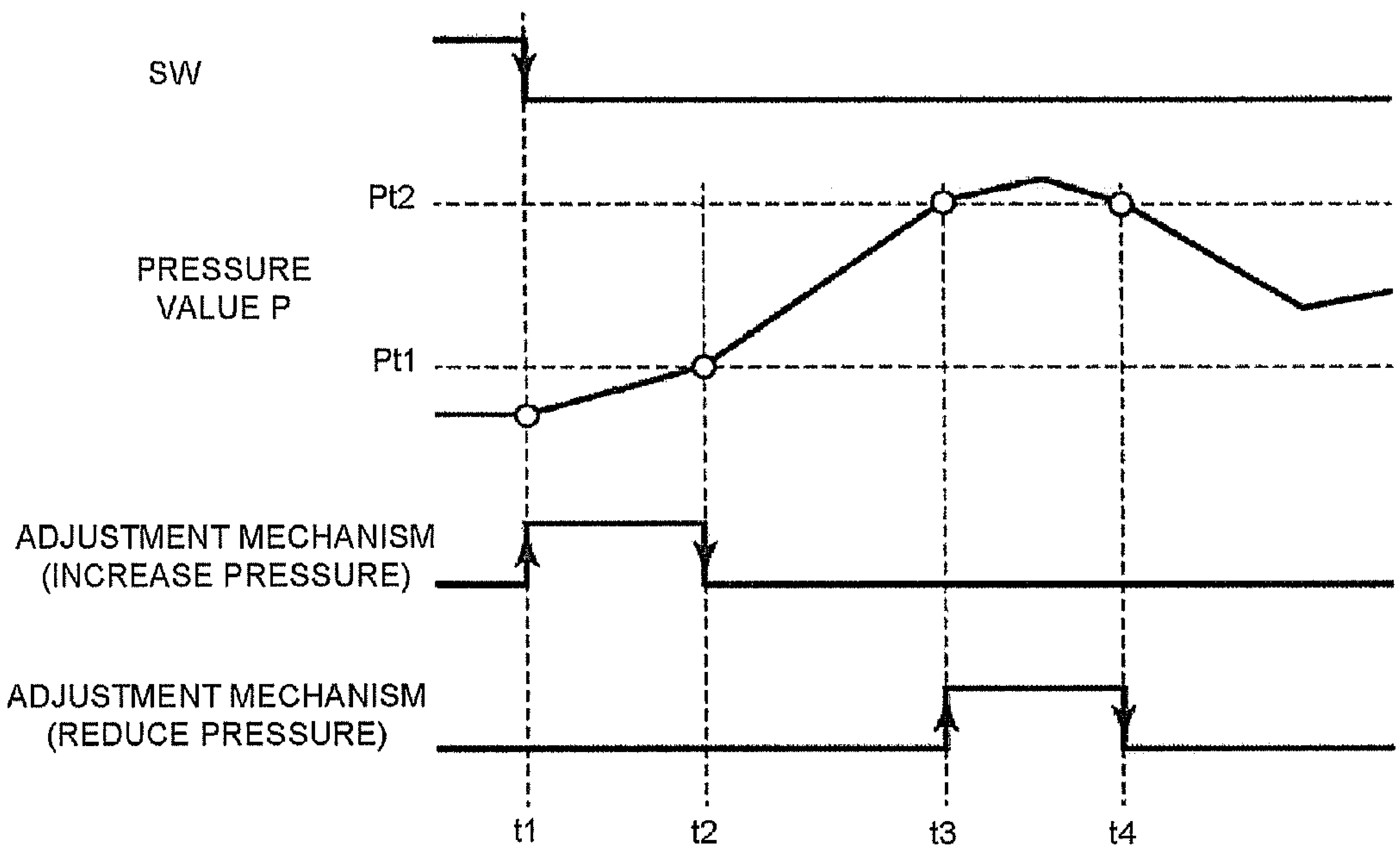

SW
Pt2
PRESSURE
VALUE P
Pt1
ADJUSTMENT MECHANISM
(INCREASE PRESSURE)
ADJUSTMENT MECHANISM
(REDUCE PRESSURE)
t1
t2
t3
t4

FIG.11

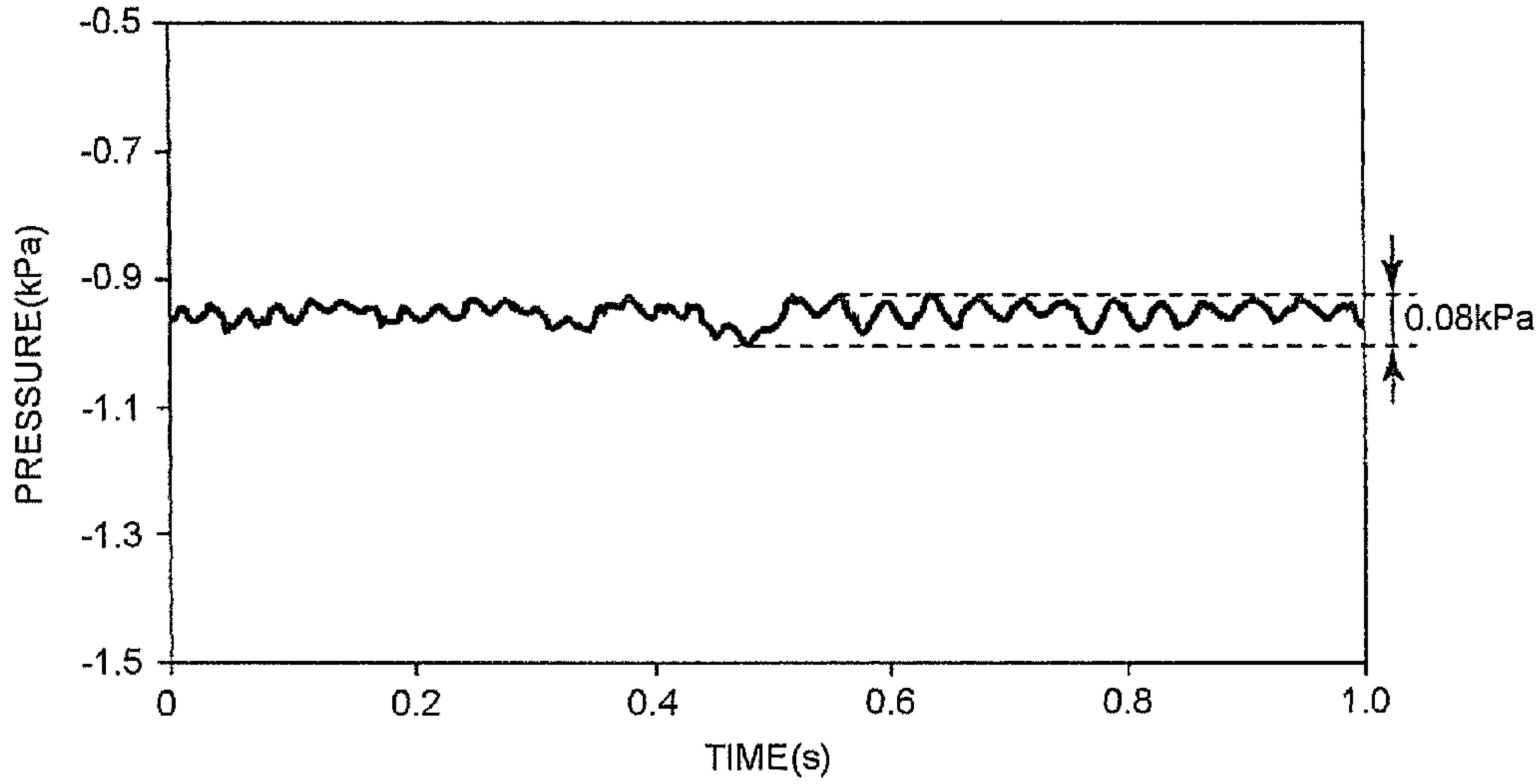

-0.5
-0.7
-0.9
-1.1
-1.3
-1.5
PRESSURE(kPa)
0.08kPa
0
0.2
0.4
0.6
0.8
1.0
TIME(s)

FIG.12

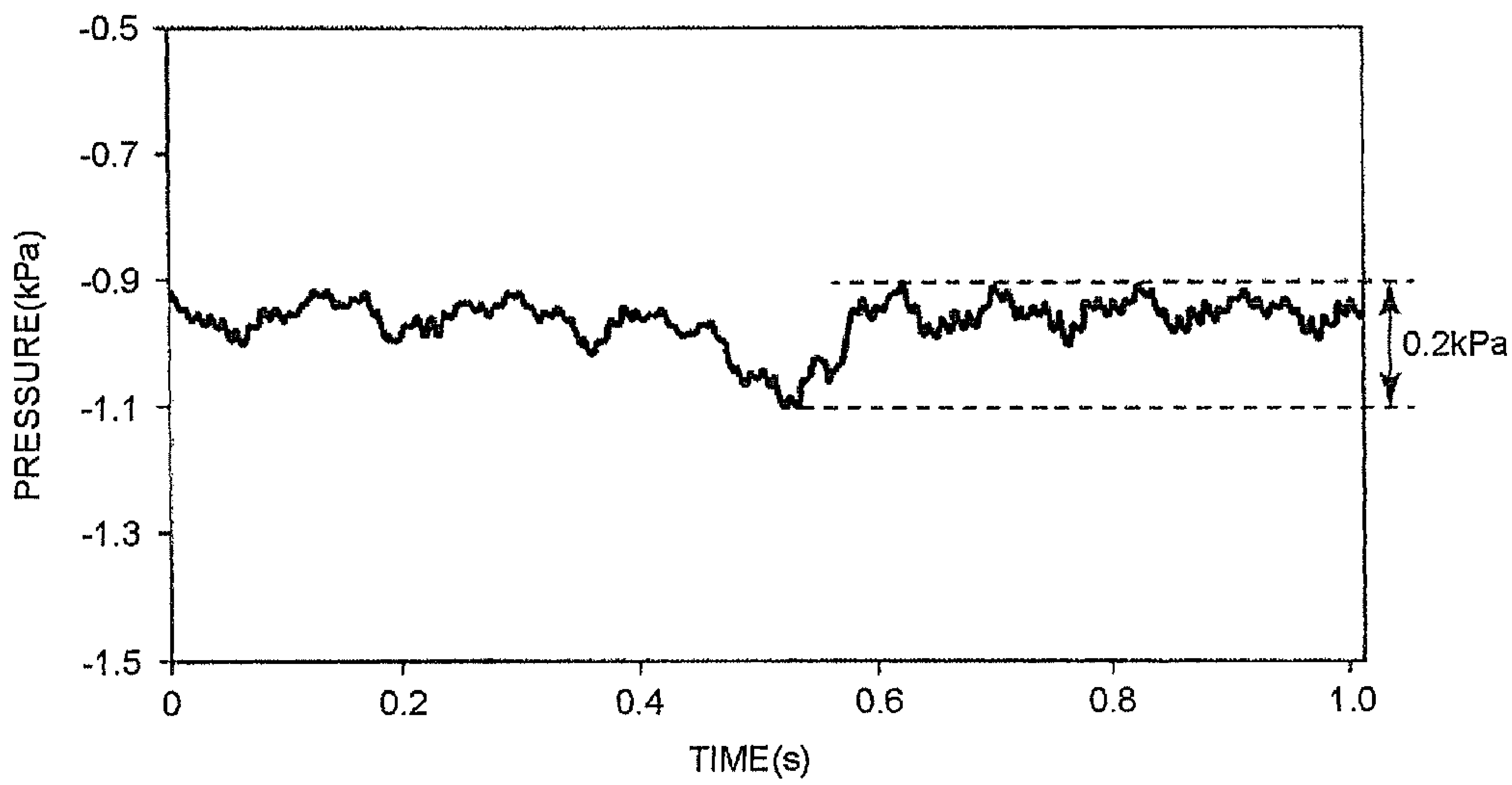
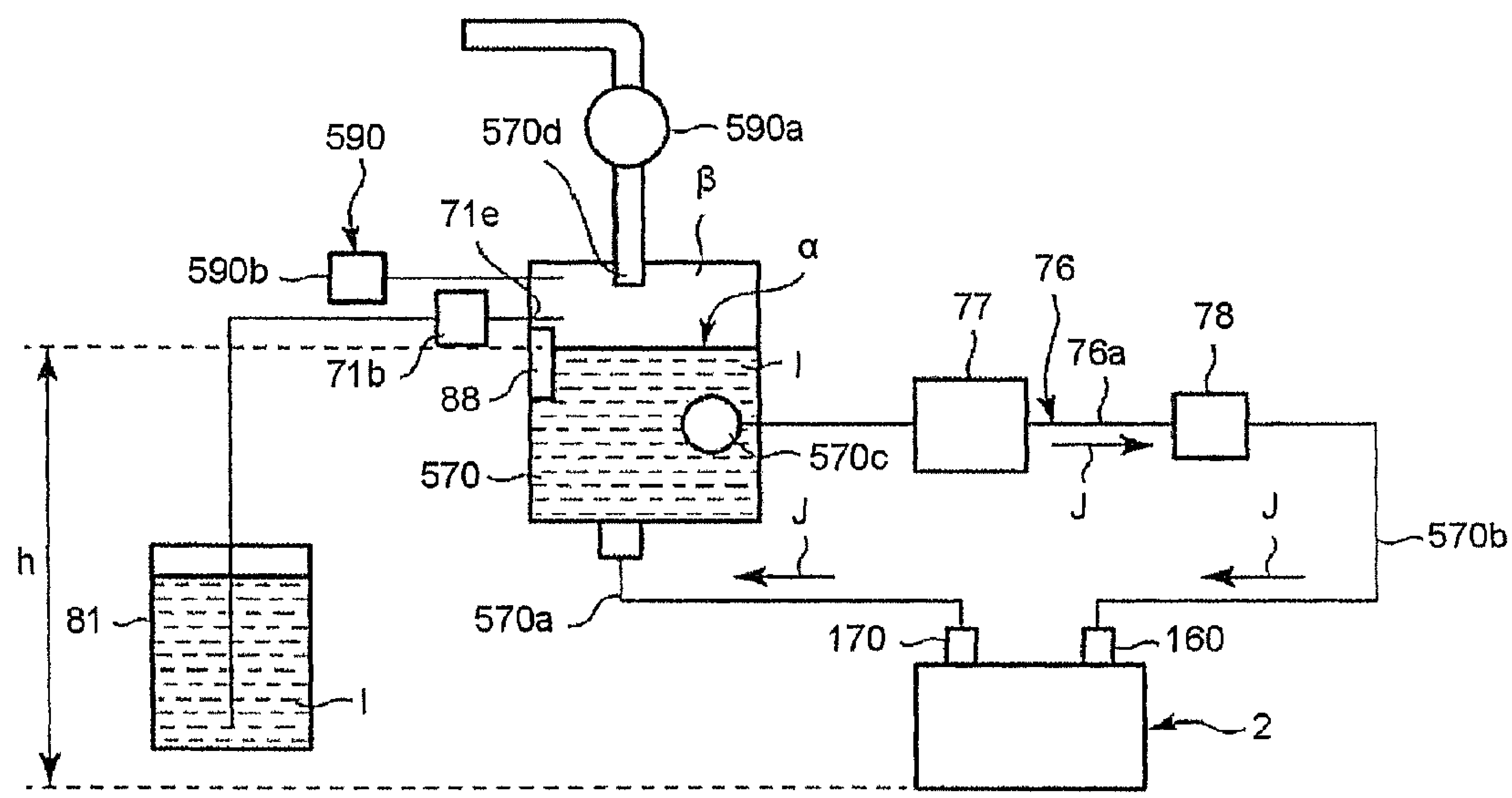

-0.5
-0.7
-0.9
-1.1
-1.3
-1.5
PRESSURE(kPa)
0.2kPa
0
0.2
0.4
0.6
0.8
1.0
TIME(s)

FIG.13


590a
570d
590
β
71e
α
590b
76
77
78
76a
71b
l
88
570c
570
J
J
570b
J
J
h
570a
81
170
160
l
2

INK CIRCULATION DEVICE AND INK EJECTION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. P2016-037819, filed Feb. 29, 2016, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to an ink circulation device and an ink ejection device.

BACKGROUND

An ink ejection device is provided to supply liquid to a liquid ejection head including a nozzle from a liquid tank and eject the liquid from the nozzle. In the ink ejection device, there is known a technology for replenishing the liquid to adjust pressure with the changing volume of liquid without stopping a printing operation if it is detected that the liquid in the liquid tank is reduced.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side view illustrating the configuration of an inkjet recording apparatus according to a first embodiment;

FIG. **2** is a plan view illustrating the configuration of the inkjet recording apparatus;

FIG. **3** is a view illustrating the configuration of an inkjet head of the inkjet recording apparatus;

FIG. **4** is a view illustrating a state in which ink remains in a nozzle of the inkjet head;

FIG. **5** is a view illustrating a state in which an ink droplet is ejected from the nozzle of the inkjet head;

FIG. **6** is a view schematically illustrating the configuration of an ink circulation device according to the first embodiment;

FIG. **7** is a view illustrating an ink circulation operation of the ink circulation device;

FIG. **8** is a block diagram illustrating a control system of the inkjet recording apparatus according to the first embodiment;

FIG. **9** is a flowchart illustrating a pressure adjusting processing of the inkjet recording apparatus;

FIG. **10** is a timing chart illustrating the pressure adjusting processing of the inkjet recording apparatus;

FIG. **11** is a graph illustrating the pressure fluctuation in the pressure adjusting processing of the inkjet recording apparatus;

FIG. **12** is a graph illustrating the pressure fluctuation in the pressure adjusting processing according to a comparison example; and

FIG. **13** is a view illustrating the configuration of an ink circulation device according to a second embodiment.

DETAILED DESCRIPTION

In accordance with an embodiment, a liquid circulation device comprises a liquid casing, a gas replenishing section and a liquid replenishing section. The liquid casing retains liquid to be supplied to a liquid ejection section for ejecting the liquid and includes a liquid chamber connected with the liquid ejection section in such a manner that the liquid can be circulated therebetween. The gas replenishing section replenishes gas to the liquid casing. The liquid replenishing section replenishes the liquid to the liquid casing. The ink circulation device increases pressure inside of the liquid casing by replenishing the gas to the liquid casing with the gas replenishing section and replenishing the liquid to the liquid casing with the liquid replenishing section. In a case of setting a diameter of a flow path between the liquid casing and the gas replenishing section as d1, a length of a flow path between the liquid casing and the gas replenishing section as L1, pressure generated by sending the gas by the gas replenishing section as ΔP1, viscosity of the gas as μ1, a diameter of the flow path between the liquid casing and the liquid replenishing section as d2, a length of the flow path between the liquid casing and the liquid replenishing section as L2, pressure generated by sending the liquid the liquid replenishing section as ΔP2, and viscosity of the liquid as μ2, the ink circulation device meets a relation $(\Delta P1*(d1)\hat{}2/L1)/(\Delta P2*(d2)\hat{}2/L2)>\mu1/\mu2$.

In accordance with another embodiment, a method of circulating liquid within an inkjet apparatus involves circulating a liquid between a liquid chamber and a liquid ejection section within a liquid casing; replenishing gas to the liquid casing; and replenishing the liquid to the liquid casing, wherein replenishing the gas to the liquid casing replenishing section and replenishing the liquid increases pressure inside of the liquid casing, and meets a relation $(\Delta P1*(d1)\hat{}2/L1)/(\Delta P2*(d2)\hat{}2/L2)>\mu1/\mu2$ in a case of setting a diameter of a flow path between the liquid casing and a gas replenishing section as d1, a length of the flow path between the liquid casing and the gas replenishing section as L1, pressure generated by sending the gas by the gas replenishing section as ΔP1, viscosity of the gas as μ1, a diameter of a flow path between the liquid casing and a liquid replenishing section as d2, a length of the flow path between the liquid casing and the liquid replenishing section as L2, pressure generated by sending the liquid by the liquid replenishing section as ΔP2, and viscosity of the liquid as μ2.

In accordance with yet another embodiment, a liquid ejection method from an inkjet apparatus involves circulating a liquid between a liquid chamber and a liquid ejection section within a liquid casing; collecting the liquid from the liquid ejection section; replenishing gas to the liquid casing; replenishing the liquid to the liquid casing; increasing pressure inside of the liquid casing by replenishing the gas to the liquid casing and replenishing the liquid to the liquid casing; and supplying the liquid to the liquid ejection section.

First Embodiment

Hereinafter, an inkjet recording apparatus **1** (ink ejection device) according to the first embodiment is described with reference to FIG. **1** to FIG. **8**. For convenience of description of each diagram, configurations are shown by being properly enlarged, reduced or omitted. Further, the same numbers are assigned to the same structures or similar structures.

FIG. **1** is a front view of the inkjet recording apparatus **1**; and FIG. **2** is a plan view of the inkjet recording apparatus **1**. As shown in FIG. **1** and FIG. **2**, the inkjet recording apparatus **1** serving as the ink ejection device is equipped with an image forming section **6**, an image receiving medium moving section **7** serving as a conveyance section and a maintenance unit **310**.

The image forming section **6** is equipped with an inkjet recording section **4**, a carriage **100** for supporting the inkjet recording section **4**, a conveyance belt **101** for enabling the carriage **100** to reciprocate in an arrow A direction and a carriage motor **102** for driving the conveyance belt **101**.

The inkjet recording section **4** is equipped with an inkjet head **2** serving as a liquid ejection section and an ink ejection section and an ink circulation device **3** serving as a circulation section. The ink circulation device **3** is arranged at the upside of the inkjet head **2** to be integrated with the inkjet head **2**. The inkjet recording section **4** ejects the ink to an image receiving medium S to form a desired image.

The inkjet recording section **4** is equipped with inkjet recording sections **4***a*, **4***b*, **4***c*, **4***d* and **4***e* for respectively ejecting cyan ink, magenta ink, yellow ink, black ink and white ink, for example. Colors or characteristics of the ink used in the inkjet recording sections **4***a*, **4***b*, **4***c*, **4***d* and **4***e* are not limited. For example, the inkjet recording section **4***e* can eject transparent glossiness ink or special ink which develops color when being irradiated with an infrared ray or an ultraviolet ray or the like in place of the white ink. The inkjet recording sections **4***a*, **4***b*, **4***c*, **4***d* and **4***e* have the same configuration although using different ink. Thus, the inkjet recording sections **4***a*, **4***b*, **4***c*, **4***d* and **4***e* are described with common symbols.

A width of the inkjet recording section **4** is narrowed by laminating the ink circulation device **3** above the inkjet head **2**. Thus, a width of the carriage **100** for supporting a plurality of the inkjet recording sections **4***a*~**4***e* in parallel can be narrowed. Through narrowing the width of the carriage **100**, the image forming section **6** can reduce a conveyance distance of the carriage **100**, and the miniaturization of the inkjet recording apparatus **1** can be obtained and the printing speed can be increased.

The image forming section **6** is equipped with ink cartridges **81** for replenishing new ink to the ink circulation device **3**. The ink cartridges **81***a*, **81***b*, **81***c*, **81***d* and **81***e* of the ink cartridge **81** respectively retain the cyan ink, the magenta ink, the yellow ink, the black ink and the white ink. The ink cartridges **81***a*, **81***b*, **81***c*, **81***d* and **81***e* have the same configuration although retaining different ink. Thus, the ink cartridges **81***a*, **81***b*, **81***c*, **81***d* and **81***e* are described with the common symbols. The ink cartridge **81** communicates with the ink circulation device **3** of the inkjet recording section **4** via a tube **82**. The ink cartridge **81** is arranged relatively lower than the ink circulation device **3** in a gravity direction.

The image receiving medium moving section **7** is equipped with a table **103** for sucking the image receiving medium S to fix it. The table **103** is arranged on a slide rail device **105** and reciprocates in an arrow B direction. The inside of the table **103** becomes negative pressure through a pump **104** to suck the image receiving medium S from a hole **110** having a small diameter on the upper surface thereof to fix it. While the inkjet recording section **4** reciprocates along the conveyance belt **101** in the arrow A direction, a distance h between a nozzle plate **52** of the inkjet head **2** and the image receiving medium S is kept constant. The inkjet head **2** is equipped with 300 nozzles **51** serving as liquid ejection sections in the longitudinal direction of the nozzle plate **52**. The longitudinal direction of the nozzle plate **52** is the same as the conveyance direction of the image receiving medium S.

The image forming section **6** forms an image on the image receiving medium S while enabling the inkjet head **2** to reciprocate in a direction orthogonal to the conveyance direction of the image receiving medium S. The inkjet head **2** ejects ink I from a nozzle **51** arranged in the nozzle plate **52** in accordance with an image forming signal to form the image on the image receiving medium S. The inkjet recording section **4** forms the image on the image receiving medium S by the total width of 300 nozzles, for example.

The maintenance unit **310** is arranged at the outside of a moving range of the table **103**, in other words, the maintenance unit **310** is arranged in a scanning range of the inkjet recording section **4** in the arrow A direction. The inkjet head **2** is opposed to the maintenance unit **310** at a standby position Q. The maintenance unit **310** is a case with the upper part thereof opened and the maintenance unit **310** can be moved up and down (an arrow C direction and an arrow D direction shown in FIG. **1**).

In a case in which the carriage **100** moves in the arrow A direction to print an image, the maintenance unit **310** moves downwards (the arrow C direction) to separate from the nozzle plate **52**. If the printing operation is ended and the inkjet head **2** returns to the standby position Q, the maintenance unit **310** moves upwards to cover the nozzle plate **52** of the inkjet head **2**. In this way, the maintenance unit **310** prevents the evaporation of the ink from the nozzle plate **52**, and prevents adhesion of dust and paper powder to the nozzle plate **52**. The maintenance unit **310** includes a function of capping the nozzle plate **52**.

The maintenance unit **310** is equipped with a blade **120** made from rubber and a waste ink receiving section **130**. The blade **120** made from rubber removes ink, dust or paper powder adhering to the nozzle plate **52** of the inkjet head **2**. The waste ink receiving section **130** receives waste ink, dust or paper powder generated when a maintenance operation is executed. The maintenance unit **310** is equipped with a mechanism for enabling the blade **120** to move to the arrow B direction and wipes the surface of the nozzle plate **52** with the blade **120**.

In order to remove the deteriorated ink in the vicinity of the nozzle, the inkjet head **2** carries out the maintenance (for example, a spit function) for forcibly enabling the ink to be ejected from the nozzle **51**. The inkjet head **2** enables a little ink to flow from the nozzle **51** to carry out the maintenance (for example, a purge function) for taking the paper powder and the dust attached to the surface of the inkjet head **2** in the flowing ink film and swabbing the paper powder and the dust with the blade **120**. The waste ink receiving section **130** collects the waste ink generated through the spit function or the purge function.

The inkjet recording apparatus **1** enables the inkjet head **2** to reciprocate in a direction orthogonal to the conveyance direction of the image receiving medium S by the image receiving medium moving section **7**, and simultaneously ejects the ink from the nozzle **51** to form an image on the image receiving medium S.

The configuration of the inkjet recording apparatus **1** is not limited. For example, the inkjet recording apparatus **1** may be an apparatus for moving a roll-shaped image receiving medium by winding the image receiving medium in a direction orthogonal to the moving direction of the inkjet recording section **4** rather than using the table **103** to move the image receiving medium. Alternatively, the inkjet recording apparatus **1** may be an apparatus for moving a sheet-like image receiving medium in a direction orthogonal to the moving direction of the inkjet recording section **4** through a platen roller.

As shown in FIG. **3** and FIG. **4**, for example, the inkjet head **2** is equipped with the nozzle plate **52** including the nozzle **51**, a substrate **60** including an actuator **54** and a manifold **61** connected with the substrate **60**. The substrate **60** is equipped with an ink flow path **180** for enabling the ink to flow between the nozzle **51** and the actuator **54**. The actuator **54** faces the ink flow path **180** and is arranged corresponding to each nozzle **51**.

The substrate **60** is equipped with a boundary wall **190** between the adjacent nozzles **51** so as to centralize the pressure generated in the ink in the ink flow path **180** through the actuator **54** in the nozzle **51**. The nozzle plate **52**, the actuator **54**, and the ink flow path **180** surrounded by the boundary wall **190** constitute the ink pressure chamber **150**. A plurality of the ink pressure chambers **150** is arranged corresponding to the individual nozzle **51***a* of the first nozzle row **57***a* and the individual nozzle **51***b* of the second nozzle row **57***b*. The first nozzle row **57***a* and the second nozzle row **57***b* respectively include 300 nozzles **51***a* and 300 nozzles **51***b*.

The substrate **60** is equipped with a common ink supply chamber **58** for supplying or delivering the ink to a plurality of the ink pressure chambers **150** and common ink chambers **59** for collecting the ink from a plurality of the ink pressure chambers **150** respectively at the first nozzle row **57***a* side and at the second nozzle row **57***b* side.

The manifold **61** is equipped with an ink supply port **160** for enabling the ink to flow in an arrow F direction and an ink discharge port **170** for discharging the ink towards an arrow G direction. The ink I is supplied from the ink circulation device **3** to the ink supply port **160**, and the ink recirculates from the ink discharge port **170** to the ink circulation device **3**. The manifold **61** is equipped with an ink distributing passage **62** for communicating from the ink supply port **160** to the common ink supply chamber **58**. The manifold **61** is equipped with the ink recirculating passage **63** for communicating from the common ink chamber **59** to the ink discharge port **170**.

In other words, the ink flow path **180** is formed at the inner side of the inkjet head **2** through the substrate **60**, the manifold **61** and the nozzle plate **52**. The ink flow path **180** includes a plurality of the ink pressure chambers **150** communicating with the nozzles **51***a* and **51***b*, the ink supply port **160** and the ink discharge port **170** formed in the manifold **61**, the common ink supply chamber **58** for communicating with a plurality of the ink pressure chambers **150**, the common ink chamber **59** for collecting the ink from a plurality of the ink pressure chambers **150**, the ink distributing passage **62** for communicating from the ink supply port **160** to the common ink supply chamber **58**, and the ink recirculating passage **63** for communicating from the common ink chamber **59** to the ink discharge port **170**.

The ink I flowing through the ink distributing passage **62** in the arrow F direction flows from the common ink supply chamber **58** into a plurality of the ink pressure chambers **150**. The ink I in the ink pressure chamber **150** that is not ejected from the nozzle **51** flows into the common ink chamber **59** to recirculate to the ink recirculating passage **63**.

The actuator **54** of the inkjet head **2** is, for example, formed by a unimorph type piezoelectric vibration plate by laminating a vibration plate **56** and a piezoelectric element **55**. The piezoelectric element **55** is, for example, composed of a piezoelectric ceramic material such as PZT (Lead Zirconate Titanate). The vibration plate **56** is, for example, formed by SiN (Silicon Nitride) and the like.

As shown in FIG. **4** and FIG. **5**, the piezoelectric element **55** is equipped with electrodes **55***a* and **55***b* at the upper surface and the lower surface thereof. In a case in which a voltage is not applied to the electrodes **55***a* and **55***b*, as shown in FIG. **4**, as the piezoelectric element **55** does not deform, the actuator **54** does not deform yet. In a case in which the actuator **54** does not deform, through surface tension of the ink, a meniscus **290** serving as an interface between the ink I and the air is formed in the nozzle **51**. The ink I in the ink pressure chamber **150** remains in the nozzle **51** through the meniscus **290**.

If a voltage (V) is applied to the electrodes **55***a* and **55***b*, the piezoelectric element **55** deforms, and the actuator **54** deforms as shown in FIG. **5**. Through the deformation of the actuator **54**, the pressure (positive pressure) applied to the meniscus **290** is higher than the atmospheric pressure, and the ink I breaks the meniscus **290** to become an ink droplet ID and is ejected from the nozzle **51**. Furthermore, the atmospheric pressure is set to zero, negative pressure refers to the pressure lower than the atmospheric pressure, and positive pressure refers to the pressure higher than the atmospheric pressure.

The inkjet head generates pressure fluctuation in the ink in the ink pressure chamber; however, the configuration thereof is not limited. The inkjet head, for example, may eject ink droplets by deforming the vibration plate through static electricity, or may eject ink droplets from the nozzle utilizing thermal energy of a heater. Further, ink viscosity varies depending on the temperature, since the ejection characteristics from the nozzle change, in order to well control the ink ejection, the inkjet head may include a temperature sensor.

As shown in FIG. **6** and FIG. **7**, the ink circulation device **3**, for example, is equipped with an ink casing **70** serving as a liquid casing constituting the liquid chamber (ink chamber), a circulation section **76** and a pressure adjustment section **90** serving as a gas replenishing section.

The ink circulation device **3** circulates the ink to supply the ink to the inkjet head **2** and adjusts the pressure of the ink pressure chamber **150** of the inkjet head **2**. The ink circulation device **3** adjusts the pressure of the ink pressure chamber **150** and adjusts the pressure of the meniscus **290** of the nozzle **51**. The ink circulation device **3** circulates the ink to supply the ink to the inkjet head **2**, and sucks the air bubbles contained in the ink I or removes a foreign matter.

In the inkjet head **2**, if the pressure (positive pressure) applied to the meniscus **290** of the nozzle **51** is higher than the atmospheric pressure, the ink I leaks out from the nozzle **51**. If the pressure (negative pressure) applied to the meniscus **290** is lower than the atmospheric pressure, the ink I maintains the meniscus **290** and stays in the nozzle **51**.

For example, if the nozzle **51** is arranged so as to eject the ink I in the gravity direction (downwards), in a case in which the pressure in the ink pressure chamber **150** is higher than −0.5 kPa (positive pressure side), the ink I leaks out from the nozzle **51** through slight vibration. In a case in which the pressure in the ink pressure chamber **150** is lower than −4.0 kPa (negative pressure side), the air bubbles are sucked from the nozzle **51**, and ejection failure of the ink occurs. The ink circulation device **3** maintains the pressure of the meniscus **290** to a range of −4.0 kPa~−0.5 kPa to prevent the unnecessary leakage of the ink or the suck of the air bubbles.

The ink casing **70** is connected with the inkjet head **2** in such a manner that the liquid can be circulated therebewteen. The ink casing **70** is equipped with an ink collecting chamber **71** for collecting the ink I from the inkjet head **2**, an ink supply chamber **72** for supplying the ink I to the inkjet head **2**, and a common wall **73** that mediates between the ink collecting chamber **71** and the ink supply chamber **72**. The ink casing **70** is sealed from outside air. The ink collecting chamber **71** retains the ink I forming a first liquid surface $\alpha 1$, and constitutes a first air chamber $\beta 1$ above the first liquid surface $\alpha 1$. The ink supply chamber **72** retains the ink I forming a second liquid surface $\alpha 2$, and constitutes a second air chamber $\beta 2$ above the second liquid surface $\alpha 2$.

The ink collecting chamber **71** is equipped with an ink recirculating path **71***a*. The ink recirculating path **71***a* communicates with the inside of the ink collecting chamber **71** and the ink discharge port **170** of the inkjet head **2**. The ink I from the inkjet head **2** recirculates to the ink collecting chamber **71** through the ink recirculating path **71***a*.

The ink collecting chamber **71** is equipped with an ink supply pump **71***b*. The ink supply pump **71***b* is an ink replenishing section serving as a liquid replenishing section. The ink collecting chamber **71** is equipped with a replenishing port **71***e* communicating with the ink cartridge **81** via the tube **82**.

The ink supply pump **71***b* replenishes new ink from the ink cartridge **81** to the ink collecting chamber **71** via the tube **82**. The ink collecting chamber **71** is equipped with a liquid feeding hole **71***c* through which the ink fed to the circulation section **76** passes. The ink collecting chamber **71** is equipped with a first communicating hole **71***d* communicating with a first pressure adjustment section **91** of a pressure adjustment section **90**.

The ink supply chamber **72** is equipped with an ink supply path **72***a*. The ink supply path **72***a* communicates with the inside of the ink supply chamber **72** and the ink supply port **160** of the inkjet head **2**. The ink I flows into the inkjet head **2** through the ink supply port **160**. The ink supply chamber **72** is equipped with a discharge hole **72***b* for discharging the ink I fed from the circulation section **76**. The ink supply chamber **72** is equipped with a second communicating hole **72***c* communicating with a second pressure adjustment section **92** of the pressure adjustment section **90**.

The ink can be well circulated between the ink collecting chamber **71** or the ink supply chamber **72** and the inkjet head. Further, the configurations of the ink collecting chamber **71** and the ink supply chamber **72** are not limited. For example, a heater for heating the ink may be included so as to maintain the temperature of the ink in a predetermined range.

By arranging the ink cartridge **81** at relatively lower side of the ink circulation device **3** in the gravity direction, water head pressure of the ink in the ink cartridge **81** is maintained to be lower than set pressure of the ink collecting chamber **71**. By arranging the ink cartridge **81** at the lower side of the ink circulation device **3**, the ink cartridge **81** supplies the new ink to the ink collecting chamber **71** only at the time the ink supply pump **71***b* drives.

The ink supply pump **71***b* is, for example, a piezoelectric pump. The ink supply pump **71***b* periodically changes volume in the pump (volume of the pump chamber) through bending piezoelectric vibration plate obtained by attaching the piezoelectric element to a metal plate. The ink supply pump **71***b* conveys the ink from the ink cartridge **81** to the pump chamber through the change of the volume of the pump chamber. The ink supply pump **71***b* sets the conveyance direction of the ink to one direction from the ink cartridge **81** to the ink collecting chamber **71** through a check valve. If the pump chamber expands through the bending of the piezoelectric vibration plate, the ink supply pump **71***b* enables the ink to flow into the pump chamber. If the pump chamber contracts through the bending of the piezoelectric vibration plate, the ink supply pump **71***b* enables the ink to flow out of the pump chamber. Through repeating the expansion and contraction of the pump chamber, the ink supply pump **71***b* feeds the ink from the ink cartridge **81** to the ink collecting chamber **71**. Further, the ink chamber (liquid chamber) for feeding the ink from the ink cartridge **81** is not limited to the ink collecting chamber **71**, and may be the ink supply chamber **72**.

The configuration or position of the ink cartridge **81** is not limited. For example, in a case in which the ink cartridge **81** is arranged at a higher position than the ink circulation device **3**, the water head pressure of the ink in the ink cartridge **81** is higher than the set pressure of the ink collecting chamber **71**. In a case in which the ink cartridge **81** is arranged at a higher position than the ink circulation device **3**, through using the water head pressure to close and open a solenoid valve, the ink can be supplied from the ink cartridge **81** to the ink collecting chamber **71**.

As shown in FIG. **7**, the circulation section **76** of the ink circulation device **3** is equipped with a circulation path **76***a* from the liquid feeding hole **71***c* of the ink collecting chamber **71** to the discharge hole **72***b* of the ink supply chamber **72**. The circulation section **76** is equipped with a circulation pump **77** and a filter **78** in the circulation path **76***a*. The circulation pump **77** is arranged across the adjacent ink collecting chamber **71** and the ink supply chamber **72**. The circulation pump **77** circulates the ink I from the ink collecting chamber **71** to the ink collecting chamber **71** via the ink supply chamber **72** and the inkjet head **2** as shown by an arrow J. The circulation section **76** sucks the ink from the liquid feeding hole **71***c* to feed the ink I to the ink supply chamber **72** through the discharge hole **72***b*. The circulation pump **77** is, for example, a tube pump, a diaphragm pump or a piston pump.

The filter **78**, for example, is arranged at the downstream side in a circulation direction with respect to the circulation pump **77** of the circulation path **76***a*, and removes the foreign matter mixed into the ink I. The filter **78** is, for example, a mesh filter made of polypropylene, nylon, polyphenylene sulfide faldo, or stainless steel.

While the ink is circulated through the circulation section **76** from the ink collecting chamber **71** to the ink supply chamber **72**, the air bubbles in the ink I rise in a direction (upwards) opposite to the gravity direction by buoyancy. The air bubbles rising through the buoyancy move to the air chamber β**1** or β**2** above the first liquid surface α**1** of the ink collecting chamber **71** or the second liquid surface α**2** of the ink supply chamber **72** to be removed from the ink.

As shown in FIG. **7**, the ink circulation device **3** is equipped with a first ink amount sensor (liquid surface sensor) **88***a* for measuring ink amount of the ink collecting chamber **71** and a second ink amount sensor (liquid surface sensor) **88***b* for measuring ink amount of the ink supply chamber **72**. The first ink amount sensor (liquid surface sensor) **88***a* and the second ink amount sensor (liquid surface sensor) **88***b* vibrate the piezoelectric vibration plates through the AC voltage, and detect the vibration of the ink transmitted to the ink collecting chamber **71** and the ink supply chamber **72** to measure the ink amount thereof, for example. The structure of the ink amount sensor is not limited, and the ink amount sensor may measure the height of the first liquid surface α**1** or the second liquid surface α**2**.

As shown in FIG. **7**, the ink circulation device **3** is equipped with a first pressure sensor **91***b* for communicating with the first communicating hole **71***d* of the ink collecting chamber **71** and a second pressure sensor **92***b* for communicating with the second communicating hole **72***c* of the ink supply chamber **72**. The first pressure sensor **91***b* serving as a pressure detection section detects pressure P1 of the first air chamber β**1** of the ink collecting chamber **71**. The second pressure sensor **92***b* serving as a pressure detection section detects pressure P2 of the second air chamber β**2** of the ink supply chamber **72**. The structures of the pressure sensors **91***b* and **92***b* are not limited. The pressure sensors **91***b* and **92***b* may use, for example, a semiconductor piezoresistance pressure sensor to output the pressure of the first air chamber β1 or the second air chamber β2 as an electrical signal. The semiconductor piezoresistance pressure sensor is equipped with a diaphragm for receiving external pressure and a semiconductor strain gauge formed on the surface of the diaphragm. The semiconductor piezoresistance pressure sensor converts change in electrical resistance due to the piezoresistance effect which occurs in strain gauge along with the deformation of the diaphragm due to the external pressure to an electric signal to detect the pressure.

The pressure of the nozzle **51** of the inkjet head **2** can be calculated through the pressure P1 of the first air chamber β1 of the ink collecting chamber **71** and the pressure P2 of the second air chamber β2 of the ink supply chamber **72**. The nozzle pressure is shown by the following equation 1.

$$L2/(L1+L2)*(P1+\rho gh1)+L1/(L1+L2)*(P2+\rho gh2) \quad \text{(Equation 1)}$$

Herein, the ratio of the length of the ink recirculating path **71***a* and the ink supply path **72***a* is L1/L2. Further, the height from the first liquid surface α1 to the nozzle **51** is set as h1, and the height from the second liquid surface α2 to the nozzle **51** is set as h2. The h1 and h2 are positive values in the gravity direction by taking the nozzle as the origin. In addition, P is a pressure value ($Pa=N/m^2$), ρ is specific gravity (kg/m^3) of the ink, g is gravitational acceleration (m/s^2), h is a height (m) from the nozzle to the liquid surface and L is the length (m) of the flow path.

The length of the ink recirculating path **71***a* is equal to that of the ink supply path **72***a*, further, in a case in which the height from the nozzle **51** to the first liquid surface α1 is equal to that from the nozzle **51** to the second liquid surface α2 (h1=h2=h), The nozzle pressure is shown by the following equation 2.

$$(P1+P2)/2+\rho gh \quad \text{(Equation 2)}$$

The pressure adjustment section **90** is equipped with a first pressure adjustment section **91** for adjusting the pressure of the ink collecting chamber **71** and a second pressure adjustment section **92** for adjusting the pressure of the ink supply chamber **72**. The first pressure adjustment section **91** is equipped with a first pressure adjustment pump **91***a*. The second pressure adjustment section **92** is equipped with a second pressure adjustment pump **92***a*. The pressure adjustment pump **91***a* or **92***a* can send the gas to the ink collecting chamber **71** or the ink supply chamber **72**, and can discharge the gas in the ink collecting chamber **71** or the ink supply chamber **72** to the outside. The pressure adjustment pumps **91***a* and **92***a* respectively send the air to the ink collecting chamber **71** and the ink supply chamber **72** to increase the pressure in the circulation path **76***a*. The first and the second pressure adjustment pumps **91***a* and **92***a* respectively release the air in the ink collecting chamber **71** and the ink supply chamber **72** to the outside to reduce the pressure in the circulation path **76***a*. The pressure adjustment pumps **91***a* and **92***a* may be, for example, the tube pump or a bellows pump.

Further, in the present embodiment, a structure in which both the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* are arranged is exemplified; however, the structure is not limited to this. For example, only one of the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* may be arranged.

With reference to the block diagram shown in FIG. **8**, a control system **200** for controlling the operation of the inkjet recording apparatus **1** is described. The control substrate **500** of the control system **200** is equipped with a microcomputer **510** serving as a control section for controlling the whole of the inkjet recording apparatus **1**, a circulation device driving circuit **540** for driving the ink circulation device **3**, an amplification circuit **541**, a moving section driving circuit **542** for driving the image receiving medium moving section **7** and a head driving circuit **543** for driving the inkjet head **2**. The inkjet recording section **4** is composed of the ink circulation device **3** and the inkjet head **2**. The microcomputer **510** is equipped with a memory **520** for storing programs or various data and an AD conversion section **530** for acquiring an output voltage from the ink circulation device **3** and the inkjet recording section **4**.

The control substrate **500** is connected with a power supply **550**, a display device **560** for displaying the status of the inkjet recording apparatus **1** and a keyboard **580** serving as an input device. The control substrate **500** is connected with the driving sections of various pumps and various sensors of the inkjet recording section **4**. The control substrate **500** is connected with the pump **104** of the image receiving medium moving section **7**, the slide rail device **105**, the driving section of the maintenance unit **310** and the carriage motor **102** of the conveyance belt **101**.

Hereinafter, a liquid ejection method of the inkjet recording apparatus **1** is described. If the inkjet recording apparatus **1** is initially enabled to carry out printing, the ink I is filled from the ink cartridge **81** into the inkjet recording section **4**. In order to fill the ink I, the microcomputer **510** returns the inkjet recording section **4** to the standby position, and raises the maintenance unit **310** in an arrow D direction to cover the nozzle plate **52**. The microcomputer **510** drives the ink supply pump **71***b* to feed the ink from the ink cartridge **81** to the ink collecting chamber **71**. If the ink I in the ink collecting chamber **71** reaches the liquid feeding hole **71***c*, the microcomputer **510** adjusts the pressure of the ink casing **70** with the pressure adjustment section **90** to drive the circulation pump **77**. If the ink reaches the liquid feeding hole **71***c* of the ink collecting chamber **71** and the discharge hole **72***b* of the ink supply chamber **72**, the microcomputer **510** completes the initial filling of the ink I.

The inkjet recording apparatus **1** initially fills the cyan ink, the magenta ink, the yellow ink, the black ink and the white ink in the ink cartridges **81***a*, **81***b*, **81***c*, **81***d* and **81***e* to the inkjet recording sections **4***a*, **4***b*, **4***c*, **4***d* and **4***e*.

In a case in which the initial filling of the ink I is completed, the pressure in the ink casing **70** is maintained at a negative pressure to an extent to which the ink I does not leak from the nozzle **51** of the inkjet head **2**, and the air bubbles from the nozzle **51** are not sucked. The nozzle **51** maintains the meniscus **290** at the negative pressure through the negative pressure of the ink casing **70**. In the state in which the initial filling of the ink I is completed, even if the power supply **550** of the inkjet recording apparatus **1** is turned off, the ink casing **70** is a closed state, and the meniscus **290** in the nozzle **51** is maintained at the negative pressure to prevent the leakage of the ink.

If the printing is started, the microcomputer **510** controls the image receiving medium moving section **7** to suck or draw the image receiving medium S to fix it on the table **103**, and enables the table **103** to reciprocate in the arrow B direction. The microcomputer **510** moves the maintenance unit **310** towards the arrow C direction. The microcomputer **510** controls the carriage motor **102** to convey the carriage **100** in a direction of the image receiving medium S and to enable the carriage **100** to reciprocate in the arrow A direction.

The microcomputer **510** selectively drives the actuator **54** of the inkjet head **2** based on an image signal corresponding to the image data stored in the memory **520** to eject the ink droplet ID from the nozzle **51** onto the image receiving medium S. The microcomputer **510** drives the circulation pump **77**. The ink I recirculating from the inkjet head **2** is circulated through the ink collecting chamber **71**, the filter **78**, the ink supply chamber **72** and supplied to the inkjet head **2**. By circulating the ink I, the inkjet recording apparatus **1** removes the air bubbles and the foreign matter mixed in the ink I to maintain the ink ejection performance well and print image quality by the inkjet recording section **4** is improved.

The pressure of the ink casing **70** varies depending on the ejection of the ink droplet ID from the nozzle **51** or the driving of the circulation pump **77**. In order to maintain the pressure of the ink casing **70** at a stable region in which the ink leakage from the nozzle **51** or the suck of the air bubbles from the nozzle **51** does not occur, the microcomputer **510** adjusts the pressure of the ink casing **70**. In addition, the microcomputer **510** switches the driving of the pressure adjustment pumps **91***a* and **92***a* of the pressure adjustment section **90** and the driving of the ink supply pump **71***b* to adjust the pressure of the ink casing **70**.

For example, if the ink droplet ID is ejected from the nozzle **51** at the time of printing, the ink amount of the ink casing **70** is instantaneously reduced, and the pressure of the ink collecting chamber **71** is reduced. If the first pressure sensor **91***b* detects the reduction in the pressure of the ink collecting chamber **71**, the microcomputer **510** drives the pressure adjustment section **90** and the ink supply pump **71***b* according to the detection results of the first pressure sensor **91***b*, the second pressure sensor **92***b*, the first ink amount sensor (liquid surface sensor) **88***a* and the second ink amount sensor (liquid surface sensor) **88***b*.

A pressure adjustment method for adjusting the pressure applied to the nozzle **51** is described with reference to FIG. **9** to FIG. **11**. FIG. **9** is a flowchart illustrating a control processing by the microcomputer in the pressure adjusting processing; and FIG. **10** is a timing chart of the pressure adjusting processing. FIG. **11** is a graph illustrating the pressure fluctuation in a case of executing the pressure adjustment by the air control and the ink replenishing control.

In the inkjet recording section **4**, a lower limit value of the stable region of the pressure value P of the nozzle **51** in which the suck of the air bubbles from the nozzle **51** or the ink leakage from the nozzle **51** does not occur is set as Pt1, and a upper limit value thereof is set as Pt2, for example.

As shown in FIG. **9** and FIG. **10**, after turning on the power supply **550** at time t**1**, based on the pressure value of the ink collecting chamber **71** detected by the first pressure sensor **91***b* and the pressure value of the ink supply chamber **72** detected by the second pressure sensor **92***b*, the pressure value P of the nozzle **51** is detected (Act 1). Then, whether the pressure value P is in the stable region, in other words, whether the pressure value P meets Pt1≤P≤Pt2 is determined (Act 2). In a case in which the pressure value P does not meet the Pt1≤P≤Pt2 (No in Act 2), whether the pressure value P is higher than the upper limit value of the stable region, in other words, whether the pressure value P meets P≥Pt2 is determined (Act 3).

In a case in which the pressure value P neither meets Pt1≤P≤Pt2 (No in Act 2) nor meets P≥Pt2 (No in Act 3), in other words, in a case in which the pressure value P is lower than the lower limit value Pt1, the microcomputer **510** drives the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* to take the outside air in the ink casing **70** to increase the pressure thereof (Act 4). The microcomputer **510** drives the ink supply pump **71***b* to replenish the new ink to the ink casing **70**, thereby increasing the pressure of the ink casing **70** (Act 5). In other words, the inkjet recording section **4** combines the use of the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* and the use of the ink supply pump **71***b* to take the outside air in the ink casing **70** and replenish the new ink to the ink collecting chamber **71** from the ink cartridge **81** while the printing is executed by ejecting the ink I from the nozzle **51** to carry out adjustment for increasing the pressure of the nozzle.

For example, at time t**2** in FIG. **10**, if the pressure value P of the nozzle **51** reaches the range of the lower limit value Pt1~the upper limit value Pt2, in other words, the pressure value P meets Pt1≤P≤Pt2 (Yes in Act 2), the microcomputer **510** stops the adjustment for increasing pressure.

For example, at time t**3** in FIG. **10**, if the pressure value P of the nozzle **51** is higher than the upper limit value Pt2 (Yes in Act 3), the microcomputer **510** drives the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* to discharge the air in the ink casing **70** to the outside, thereby reducing the pressure of the nozzle **51** (Act 6).

For example, at time t**4** in FIG. **10**, if the pressure value P of the nozzle **51** reaches the range of the lower limit value Pt1~the upper limit value Pt2 (Yes in Act 2), the microcomputer **510** stops the adjustment for reducing pressure. The foregoing operations (Act 1~Act 6) are repeated until the termination (Act 7) due to power off or the like.

Herein, through combining the driving of the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a* and the driving of the ink supply pump **71***b*, it is considered that the reason why the responsiveness of the pressure adjustment is quickened is difference in viscosity of the air and that of the liquid. The flow rate of a circular tube can be derived by the following equation 3 of Hagen-Poiseuille.

$$Q=\pi*(d)^4*\Delta P/(128*\mu*L) \quad \text{(Equation 3)}$$

In the above equation, Q is flow rate of the circular tube (m^3/s), d is a diameter (m) of the circular tube, ΔP is differential pressure (Pa) between both ends of the circular tube, μ is viscosity (Pa*s), and L is the length (m) of the circular tube.

The flow rate can be derived even by the following equation 4 with a flow velocity.

$$Q=\tfrac{1}{4}*(d)^2*\pi*v \quad \text{(Equation 4)}$$

In the above equation, v is flow velocity (m/s).

Based on the equation 3 and the equation 4, as shown in the equation 5, the flow velocity v can be indicated by d, ΔP, μ and L.

$$v=(d)^2*\Delta P/(32*\mu*L) \quad \text{(Equation 5)}$$

In the equation 5, if the flow velocity v1 of the air is quicker than the flow velocity v2 of the liquid, the responsiveness of the pressure adjustment of the air is faster. If the diameter of the opening of the path for sending the air is set as d1, the diameter of the opening of the path at an ink chamber side for sending the liquid is set as d2, the length of the path for sending the air is set as L1, the length of the path at the ink chamber side for sending the liquid is set as L2, the pressure generated by sending the air is set as ΔP1, the pressure generated by sending the liquid is set as ΔP2, the viscosity of the air is set as μ1, and the viscosity of the liquid is set as μ2, it can be said that the responsiveness of the air is quicker if the relation of the following equation 6 holds compared with the equation 5.

$$v1/v2(\Delta P1*(d1)^2/\mu1*L1)/(\Delta P2*(d2)^2/\mu2*L2)> 1.0 \Leftrightarrow (\Delta P*(d1)^2/L1)/(\Delta P2*(d2)^2/L2)>\mu1/\mu2 \quad \text{(Equation 6)}$$

The inkjet recording apparatus **1** according to the present embodiment meets the relation of the following equation 7.

$$(\Delta P1*(d1)^2/L1)/(\Delta P2*(d2)^2/L2)>\mu1/\mu2 \quad \text{(equation 7)}$$

In the equation 7, the diameter of the port of the gas replenishing section is set as d1, the length of the path between the liquid chamber and the gas replenishing section is set as L1, the pressure generated by sending the gas by the gas replenishing section is set as ΔP1, the viscosity of the air is set as μ1 and then, the bore diameter between the liquid chamber and the liquid replenishing section is set as d2, the length of the path between the liquid chamber and the liquid replenishing section is set as L2, the pressure generated by sending the liquid by the liquid replenishing section is set as ΔP2, and the viscosity of the liquid is set as μ2.

In the inkjet recording apparatus **1**, d1 (mm) is the diameter of the first communicating hole **71***d* or the second communicating hole **72***c*. L1 (mm) is a length of the flow path from the pressure adjustment pump **91***a* to the communicating hole **71***d* of the ink casing **70** or from the pressure adjustment pump **92***a* to the communicating hole **72***c*. For example, in the present embodiment, as for d1, L1, ΔP*(d)^2/L is calculated for the two pressure adjustment sections **91** and **92** and the smaller d and L are used as d1 and L1 in the equation 7.

ΔP1 (kPa) is generated by sending the air by the first pressure adjustment pump **91***a* and the second pressure adjustment pump **92***a*. d2 (mm) is the diameter of the replenishing port **71***e* which communicates with the tube **82** of the ink casing. L2 (mm) is the length of the flow path from the replenishing port **71***e* which communicates with the tube **82** of the ink casing **70** to the ink supply pump **71***b*. ΔP2 (kPa) is the pressure of the ink supply pump **71***b*. *μ*2 is the viscosity of the ink.

As μ1 is the viscosity of the air in the atmosphere, in a case in which the value thereof is treated as a fixed value 0.018 (mPa*s), in order to satisfy the condition of (the equation 7), the value of (v1/v2) needs to be greater than the values in a table 1 with respect to the viscosity of the liquid.

TABLE 1

μ2 (mPa * s)	v1/v2
1	1.0E+00
2	1.8E−02
3	9.0E−03
4	6.0E−03
5	4.5E−03
10	3.6E−03
20	1.8E−03
30	9.0E−04
40	6.0E−04
50	4.5E−04

For example, with the ink the viscosity of which is equal to or lower than 5 mPa*s, the relation in which the responsiveness of the pressure control by the air becomes faster than the responsiveness of the pressure control by the ink needs to have the relation of d1, d2, L1, 12, ΔP1 and ΔP2 with which v1/v2 is larger than 4.5×10^{-3}.

The values in the present embodiment are shown in a table 2.

TABLE 2

d1 (mm)	1
L1 (mm)	2
⊿P1 (kPa)	50

TABLE 2-continued

d2 (mm)	2
L2 (mm)	2
⊿P2 (kPa)	10

Herein, the value of (v1/v2) is 1.25, and the value thereof is larger than all the values in a region of the viscosity of 1~50 mPa*s in the table 1, thus, it can be said that the responsiveness of the pressure control by the air is faster than the responsiveness of the pressure control by the liquid having the viscosity of 1~50 mPa*s.

According to the inkjet recording apparatus **1** in the present embodiment, it is possible to fasten the responsiveness of the pressure adjustment and reduce the fluctuation value of the pressure at the time of ejecting the liquid by combining the liquid replenishment and the gas replenishment. In the inkjet recording apparatus **1**, as the fluctuation value of the pressure is small, the variation in ejection volume of the ink I ejected from the nozzle is small, and the good images can be obtained. Therefore, the inkjet recording apparatus **1** according to the present embodiment reduces the variation in the ejection volume to be capable of suppressing the image disturbance.

FIG. **11** is a graph illustrating the pressure fluctuation in the pressure adjusting processing according to the present embodiment. In FIG. **11**, the horizontal axis indicates time (s), and the vertical axis indicates the pressure value (kPa) of the nozzle. The fluctuation value in FIG. **11** is calculated through a moving average of the variation values in order to cancel the pressure fluctuation due to the circulation pump **77**. As shown in FIG. **11**, in a case of carrying out the adjustment for increasing the pressure by combining the liquid replenishment and the gas replenishment, in an environment in the embodiment, the fluctuation value is about 0.08 kPa.

FIG. **12** is a graph illustrating the pressure fluctuation in a case of carrying out the adjustment for increasing the pressure only by replenishing the new ink from the ink cartridge to the ink collecting chamber as a comparison example. In FIG. **12**, the horizontal axis indicates time (s), and the vertical axis indicates the pressure value (kPa) of the nozzle. The fluctuation value in FIG. **12** is calculated through a moving average of the variation values in order to cancel the pressure fluctuation due to the circulation pump **77**. As shown in FIG. **12**, the fluctuation value at the time of adjusting the pressure only due to the replenishment of the ink is about 0.2 kPa.

According to FIG. **11** and FIG. **12**, it can be known that the inkjet recording apparatus **1** according to the present embodiment can suppress the pressure fluctuation.

The inkjet recording section **4** can replenish the new ink I from the ink cartridge **81** to the inside of the ink casing **70** even during the pressure adjustment in the printing operation. Therefore, the inkjet recording section **4** can replenish the ink I to the inside of the ink casing **70** while adjusting the pressure P of the nozzle **51** without stopping the printing operation and can prevent the reduction of the print production efficiency of the inkjet recording apparatus **1**.

Furthermore, in the inkjet recording apparatus **1**, through carrying out a liquid filling processing based on the liquid surface position of the ink casing **70**, the ink amount of the ink casing **70** can be maintained in the appropriate range.

Second Embodiment

Hereinafter, the inkjet recording apparatus **1** and an ink circulation device **3**A according to the second embodiment of the present invention is described with reference to FIG. **13**. FIG. **13** is a view schematically illustrating the ink circulation in the ink circulation device **3**A according to the second embodiment. The present embodiment is different from the first embodiment only in that an ink casing **570** is common at the collecting side and the supply side, and the configurations of the other devices and various processing procedures or the control methods are the same as the foregoing first embodiment, and thus, the descriptions thereof are omitted.

The ink circulation device **3**A according to the second embodiment is equipped with an ink casing **570** constituting the liquid chamber (ink chamber), a circulation section **576** and a pressure adjustment section **590** serving as a gas replenishing section.

The ink casing **570** is sealed from the outside air. The ink casing **570** retains the ink I forming a liquid surface α and constitutes an air chamber β above the liquid surface α.

The ink casing **570** is equipped with an ink recirculating path **570***a* communicating with the ink discharge port **170** of the inkjet head **2** to collect the ink I from the inkjet head **2**. The ink casing **570** is equipped with an ink supply path **570***b* communicating with ink supply port **160** of the inkjet head **2**. The ink casing **570** is equipped with a communicating hole **570***d* communicating with a pressure adjustment section **590**. A pressure sensor **590***b* serving as the pressure detection section is arranged in the ink casing **570**.

A circulation section **576** is connected with the inkjet head **2** and the ink casing **570**. The circulation section **76** in the ink circulation device **3**A is arranged between the ink casing **570** and the inkjet head **2**. The circulation section **76** is equipped with the circulation path **76***a*, the circulation pump **77** and the filter **78** arranged in the circulation path **76***a*.

The pressure adjustment section **590** is equipped with a pressure adjustment pump **590***a*. The pressure adjustment pump **590***a* may be, for example, a tube pump or a bellows pump. The pressure adjustment pump **590***a* sends the air into the ink chamber in the ink casing **570** to increase the pressure in the circulation path **76***a*. The pressure adjustment pump **590***a* releases the air in the ink casing **570** to the outside to reduce the pressure in the circulation path **76***a*.

Similar with the ink circulation device **3**, the ink circulation device **3**A according to the present embodiment meets the relation of

$$(\Delta P1^*(d1)\hat{}2/L1)/(\Delta P2^*(d2)\hat{}2/L2)>\mu 1/\mu 2 \qquad \text{(equation 7).}$$

Herein, in the equation 7, the bore diameter of the gas replenishing section is set as d1, a length of the path between the liquid chamber and the gas replenishing section is set as L1, pressure generated by sending the gas by the gas replenishing section is set as ΔP1, viscosity of the gas is set as μ1, and then, the bore diameter between the liquid chamber and the liquid replenishing section is set as d2, a length of the path between the liquid chamber and the liquid replenishing section is set as L2, pressure generated by sending the liquid the liquid replenishing section is set as ΔP2, and viscosity of the liquid is set as μ2.

In other words, in the ink circulation device **3**A, d1 (mm) is the diameter of the communicating hole **570***d*. L1 (mm) is a length of the flow path from the pressure adjustment pump **590***a* to the communicating hole **570***d* of the ink casing **570**. ΔP1 (kPa) is generated by sending the air by the pressure adjustment pump **590***a*. d2 (mm) is the diameter of the replenishing port **71***e* which communicates with the tube **82** of the ink casing **570**. L2 (mm) is the length of the flow path from the replenishing port **71***e* which communicates with the tube **82** of the ink casing **570** to the ink supply pump **71***b*. ΔP2 (kPa) is the pressure of the ink supply the pump **71***b*. μ2 is the viscosity of the ink.

In addition, the configuration of each section is same as that of the inkjet recording apparatus **1** according to the first embodiment. In the present embodiment, the ink I from the inkjet head **2** recirculates to the ink casing **570** through the ink recirculating path **570***a*. The ink I flows to the inkjet head **2** through the ink supply path **570***b*.

In the present embodiment, as shown in FIG. **9** and FIG. **10**, the microcomputer **510** detects the pressure value P of the nozzle **51** based on the pressure value of the ink casing **570** detected by the pressure sensor **590***b* (Act 1). Then, whether the pressure value P is in the stable region, in other words, whether the pressure value P meets Pt1≤P≤Pt2 is determined (Act 2). In a case in which the pressure value P does not meet the Pt1≤P≤Pt2, whether the pressure value P is higher than the upper limit value of the stable region, in other words, whether the pressure value P meets P≥Pt2 is determined (Act 3). In a case in which the pressure value P neither meets Pt1≤P≤Pt2 (No in Act 2) nor meets P≥Pt2 (No in Act 3), in other words, in a case in which the pressure value P is lower than the lower limit value Pt1, the microcomputer **510** drives the pressure adjustment pump **590** to take the outside air in the ink casing **570** to increase the pressure thereof (Act 4). The microcomputer **510** drives the ink supply pump **71***b* to replenish the new ink in the ink casing **570**, thereby increasing the pressure of the ink casing **570** (Act 5). In other words, the inkjet recording section **4** combines the use of the pressure adjustment pump **590***a* and the use of the ink supply pump **71***b* to take the outside air in the ink casing **570** and replenish the new ink to the ink collecting chamber **71** from the ink cartridge **81** while the printing is executed by ejecting the ink I from the nozzle **51** to carry out adjustment for increasing the pressure of the nozzle. The same effect as the first embodiment can be realized even in the present embodiment.

The configurations of the ink circulation devices according to the embodiments described above are not limited. For example, the liquid chamber and the liquid ejection section may not be integrally formed as long as the liquid can be replenished to the liquid chamber and can be circulated. The ink circulation device can also eject liquid other than ink. The liquid ejection device for ejecting the liquid other than the ink may be, for example, a device for ejecting the liquid containing conductive particles for forming a wiring pattern of the print wiring substrate. Moreover, the structure of the ink casing is not limited to the above. For example, the ink casing may include a heater for heating the ink so as to keep the temperature of the ink in the predetermined range.

For example, a case in which the diameter of the flow path is constant is exemplified in the above embodiments; however, it is not limited to that. For example, for the diameters d1 and d2 of the flow paths, in a case in which the diameter of the flow path changes, the diameters of any locations such as the minimum diameter and the maximum diameter can be set as d1 and d2, respectively.

With respect to any figure or numerical range for a given characteristic, a figure or a parameter from one range may be combined with another figure or a parameter from a different range for the same characteristic to generate a numerical range.

Other than in the operating examples, or where otherwise indicated, all numbers, values and/or expressions referring to quantities of ingredients, reaction conditions, etc., used in the specification and claims are to be understood as modified in all instances by the term "about."

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the invention. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the invention. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention.

What is claimed is:

1. A liquid circulation device, comprising:

a liquid casing configured to retain liquid for delivery to a liquid ejection section for ejecting the liquid and include a liquid chamber connected with the liquid ejection section in such a manner that the liquid can be circulated therebetween;

a gas replenishing section configured to replenish gas to the liquid casing; and

a liquid replenishing section configured to replenish the liquid to the liquid casing, wherein

the liquid circulation device increases pressure inside of the liquid casing by replenishing the gas to the liquid casing with the gas replenishing section and replenishing the liquid to the liquid casing with the liquid replenishing section, and meets a relation $(\Delta P1^*(d1)^\wedge 2/L1)/(\Delta P2^*(d2)^\wedge 2/L2)>\mu 1/\mu 2$ in a case of setting a diameter of a flow path between the liquid casing and the gas replenishing section as d1, a length of the flow path between the liquid casing and the gas replenishing section as L1, pressure generated by sending the gas by the gas replenishing section as ΔP1, viscosity of the gas as μ1, a diameter of a flow path between the liquid casing and the liquid replenishing section as d2, a length of the flow path between the liquid casing and the liquid replenishing section as L2, pressure generated by sending the liquid by the liquid replenishing section as ΔP2, and viscosity of the liquid as μ2.

2. The liquid circulation device according to claim **1**, wherein

the gas replenishing section which can discharge the air of the liquid chamber adjusts the pressure in the liquid casing by the replenishment of the liquid, the replenishment of the gas and the discharge of the gas.

3. The liquid circulation device according to claim **1**, further comprising

a pressure detection section configured to detect the pressure in the liquid casing; and

a control section configured to control the gas replenishment section based on the pressure in the liquid casing detected by the pressure detection section.

4. The liquid circulation device according to claim **2**, further comprising

a pressure detection section configured to detect the pressure in the liquid casing; and

a control section configured to control the gas replenishment section based on the pressure in the liquid casing detected by the pressure detection section.

5. The liquid circulation device according to claim **1**, wherein

the liquid casing forms a collecting chamber for collecting the liquid from the liquid ejection section and a supply chamber for supplying the liquid to the liquid ejection section.

6. A liquid ejection apparatus comprising:

a liquid ejection section comprising a nozzle for ejecting liquid; and

a liquid circulation device, wherein

the liquid circulation device further comprising:

a liquid casing configured to retain liquid for delivery to a liquid ejection section for ejecting the liquid and to include a liquid chamber connected with the liquid ejection section in such a manner that the liquid can be circulated therebetween;

a gas replenishing section configured to replenish gas to the liquid casing; and

a liquid replenishing section configured to replenish the liquid to the liquid casing, wherein

the liquid circulation device increases pressure of the inside of the liquid casing by replenishing the gas to the liquid casing with the gas replenishing section and replenishing the liquid to the liquid casing with the liquid replenishing section, and meets a relation $(\Delta P1^*(d1)^\wedge 2/L1)/(\Delta P2^*(d2)^\wedge 2/L2)>\mu 1/\mu 2$ in a case of setting a diameter of a flow path between the liquid casing and the gas replenishing section as d1, a length of the flow path between the liquid casing and the gas replenishing section as L1, pressure generated by sending the gas by the gas replenishing section as ΔP1, viscosity of the gas as μ1, a diameter of a flow path between the liquid casing and the liquid replenishing section as d2, a length of the flow path between the liquid casing and the liquid replenishing section as L2, pressure generated by sending the liquid by the liquid replenishing section as ΔP2, and viscosity of the liquid as μ2.

7. The liquid ejection apparatus according to claim **6**, wherein

the gas replenishing section which can discharge the air of the liquid chamber adjusts the pressure in the liquid casing through the replenishment of the liquid, the replenishment of the gas and the discharge of the gas.

8. The liquid ejection apparatus according to claim **6**, further comprising

a pressure detection section configured to detect the pressure in the liquid casing; and

a control section configured to control the gas replenishment section based on the pressure in the liquid casing detected by the pressure detection section.

9. The liquid ejection apparatus according to claim **7**, further comprising

a pressure detection section configured to detect the pressure in the liquid casing; and

a control section configured to control the gas replenishment section based on the pressure in the liquid casing detected by the pressure detection section.

10. The liquid ejection apparatus according to claim **6**, wherein

the liquid casing forms a collecting chamber for collecting the liquid from the liquid ejection section and a supply chamber for supplying the liquid to the liquid ejection section.

11. A method of circulating liquid within an injet apparatus, comprising:

circulating a liquid between a liquid chamber and a liquid ejection section within a liquid casing;

replenishing gas to the liquid casing; and

replenishing the liquid to the liquid casing, wherein

replenishing the gas to the liquid casing replenishing section and replenishing the liquid increases pressure inside of the liquid casing, and meets a relation $(\Delta P1^*(d1)^\wedge 2/L1)/(\Delta P2^*(d2)^\wedge 2/L2)>\mu 1/\mu 2$ in a case of setting a diameter of a flow path between the liquid casing and a gas replenishing section as d1, a length of the flow path between the liquid casing and the gas replenishing section as L1, pressure generated by sending the gas by the gas replenishing section as ΔP1, viscosity of the gas as μ1, a diameter of a flow path between the liquid casing and a liquid replenishing section as d2, a length of the flow path between the liquid casing and the liquid replenishing section as L2, pressure generated by sending the liquid by the liquid replenishing section as ΔP2, and viscosity of the liquid as μ2.

12. The method according to claim **11**, wherein the liquid comprises ink.

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